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PAPERS IN PRESS FOR FORTHCOMING ISSUES

Caribbean Research Project. By H. H. Hess and J. C. Maxwell

Geology of the Caracas Region, Venezuela. By Gabriel Dengo

Geology of the Los Teques-Cua Region, Venezuela. By Raymond J. Smith

Geology of the St. Bartholomew, St. Martin, and Anguilla, Lesser Antilles. By Robert A. Christman

Geology of the Agua Fria Quadrangle, Brewster County, Texas. By C. Gardley Moon

Bibliography and Index of Literature on Uranium and Thorium, and Radioactive Occurrences in the U. S. Part I. Arizona, Nevada, and New Mexico. By Margaret Cooper

Beaverhead Formation, a Laramide Deposit in Beaverhead County, Montana. By W. R. Lowell and M. R. Klepper

San Andreas, Garlock, and Big Pine Faults, California. By Mason L. Hill and T. W. Dibblee, Jr.

Siliceous Sediments of Ouachita Facies in Oklahoma. By August Goldstein, Jr., and Thomas A. Hendricks

Geology of the Chloride Quadrangle, Arizona. By Blakemore E. Thomas

TABLE 1.—SUMMARY OF TERMINOLOGY AND KNOWN

Details are presented in papers in this issue by Applin (Mesozoic of Florida and Georgia), Toulmin
Gulf Coastal Plain), and Guzmán (Mexico). All volumes in cubic miles.

Mexico		Western Gulf		C		
Post-Oligocene	20,400+	Plio-Pleistocene	6,000+	Quaternary		
		Later Miocene	14,000+	NEOGENE	Mio-Pliocene	
					U. Fleming	
					L. Fleming	
		Hackberry-Frio	37,000+		U. Catahoula	
					L. Catahoula	
Oligocene	48,700+			PALEOGENE	Chickasawhay	
		Vicksburg	8,000+		Vicksburgian-U	
		Jackson	14,000+			
Eocene	92,400+	Claiborne	43,000+		Middle Eocene	
		Wilcox	64,000+		Lower Eocene-L	
		Midway	25,000+			
Upper Cretaceous	44,800+	Gulf Cretaceous	34,000+	Gulf Series		
Middle & Lower Cretaceous		Comanche Cretaceous	97,000+	Comanche Series Fredericksburg-W Washita		
(Coahuila & Comanche Series)	65,800+			Trinity Coahuila Series (Ho		
Upper Jurassic	31,800+	Jurassic	111,000+	Jurassic Cotton Valley-Ha Smackover-Norph pre-Upper Jurassic(		
				TRIASSIC—NOT KNOWN		
Total Cenozoic	161,500+	Total Cenozoic	211,000+	Total Cenozoic		
Total Cretaceous	110,600+	Total Cretaceous	131,000+	Total Cretaceous		
Total Jurassic	31,800+	Total Jurassic *et al.*	111,000+	Total Jurassic, *et al*		

AND KNOWN VOLUMES OF MESOZOIC AND CENOZOIC SEDIMENTS

eorgia), Toulmin (Cenozoic of Florida and Georgia), Murray (Central Gulf Coastal Plain), Colle *et al.* (Western

U. S. A.					
Central Gulf		Georgia and Florida			
ternary	4,000+	Recent-Pleistocene-Pliocene	600–670+	TERTIARY	CENOZOIC
Mio-Pliocene	4,700+				
U. Fleming	3,300+				
L. Fleming	4,850+	Miocene	4700–5000+		
U. Catahoula	8,075+				
L. Catahoula	5,650+				
Chickasawhay	4,425+	Oligocene	2100–2230+		
Vicksburgian-Upper Eocene	5,600+				
		Upper Eocene	3800–4500+		
Middle Eocene	16,925+	Middle Eocene	13,500–14,700+		
Lower Eocene-Paleocene	47,875+	Lower Eocene	10,000–10,500+		
		Paleocene	13,300–14,400+		
f Series	40,175+	Gulf Series	30,000–35,000+	CRETACEOUS	MESOZOIC
anche Series edericksburg-Washita-post-Washita	14,475+	Comanche Series	20,000–25,000+		
inity	18,800+				
huila Series (Hosston-Sligo)	25,900+				
ssic		pre-Cretaceous	10,000–15,000+	JURASSIC *et al.*	
otton Valley-Haynesville	23,150+				
nackover-Norphlet	10,875+				
Upper Jurassic(?)	26,500+				

NOT KNOWN TO BE PRESENT

al Cenozoic	105,400+	Total Cenozoic	48,000–52,000
al Cretaceous	99,350+	Total Cretaceous	50,000–60,000+
al Jurassic, *et al.*	60,525+	Total Jurassic (Total pre-Cretaceous)	10,000–15,000+

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 63, PP. 1157-1158 DECEMBER 1952

SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF UNITED STATES AND MEXICO

Foreword and Summary

By Grover E. Murray

Because many basic problems of earth history and continental development are either directly or indirectly relatable to geosynclinal sedimentation, the Council and Program Committee of The Geological Society of America authorized a session on *Sedimentary Volumes* for the Annual Meeting of 1950. The wealth of available subsurface data in the Gulf Coastal Plain of the United States and Mexico made this a logical area for study. I was asked to organize and supervise the program. The papers presented are published here in the order of delivery.

The immediate objectives of the session were studies of the distribution, thickness, volume, and general character of Mesozoic and Cenozoic sedimentary rocks of the Gulf Coastal Plain province rimming the western and northern shores of the Gulf of Mexico. Secondary objectives were: (1) the assembly and recording of all available data in a form usable for students of earth development; (2) delineation of "floods" of clastic sediments and their relation to orogenic and diastrophic movements within the continent; (3) determination of the weight of the sediments and possible isostatic implications; (4) procurement of knowledge as to the mode of accumulation and the manner of development of large sedimentary masses and the light they shed on geosynclinal development; and (5) the distribution of negative and positive areas or elements within the area of sedimentary accumulation and their relationships to the ultimate development of belts of folding.

Data were obtained primarily from exploratory wells drilled in search of hydrocarbons or other mineral deposits and secondarily from outcrop measurements. Accuracy and data are variable, stratigraphically and areally. Roughly, the accuracy is proportional to the amount of data available. So far as practicable, isopachous contours are generalized for demonstrable trends founded on known data. Interpretations and inferences are based on parallel extensions of determinable contours.

Boundaries of all categories of stratigraphic units are subject to interpretation and revision. Changes would be compensatory for adjacent units and probably would not affect any one map greatly. Where possible, recognized and accepted stratigraphic units of regional extent were utilized by the individual participants. Facies variations, undetermined correlations, and classificatory disagreements caused certain deviations in his policy. The stratigraphic nomenclature employed by each participant and the relationships of these terms is summarized in Table 1.

Total known volumes of the emerged portion (that part above the sea) of the coastal plain between the Yucatan peninsula and the State of Georgia approximate 1,140,000 cubic miles. The presence of an additional 500,000 cubic miles can be reasonably demonstrated. As no appreciable quantity of igneous rocks is known to be present in these Mesozoic and Cenozoic sediments, no deduction of igneous rock volume has been made. Summaries of these volumes are presented in Table 1. More detailed analyses of the known volumes are given in the individual papers along with certain inferred volumes.

Geophysical and exploratory well data suggest the total sedimentary volume of the submerged portion of the province will equal, and probably exceed, that of the emerged area.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 63, PP. 1159-1164, 3 FIGS. DECEMBER 1952

SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF THE UNITED STATES AND MEXICO

PART I: VOLUME OF MESOZOIC SEDIMENTS IN FLORIDA AND GEORGIA

BY PAUL L. APPLIN

ABSTRACT

Mesozoic sedimentary rocks are present throughout Florida and the Coastal Plain of Georgia, but chiefly in the subsurface in an area of approximately 93,500 square miles. The Mesozoic rocks in this area belong, for the most part, to the Gulf and Comanche series of the Cretaceous system. Rocks tentatively classified as part Jurassic and part Triassic underlie the Comanche series in parts of Florida and Georgia. In the northern part of the Georgia Coastal Plain, an irregular outcrop belt of sandstone and shale belonging to the early Upper Cretaceous Tuscaloosa formation borders on the south the crystalline rocks of the Piedmont. Southward from its outcrop in western Georgia, the Tuscaloosa formation dips under roughly parallel belts of the progressively younger Eutaw formation and formations equivalent to the Selma group of the Gulf series. In central and eastern Georgia, the Eutaw formation and formations equivalent to the Selma group are covered by overlaps of Tertiary formations. Conclusions in regard to the stratigraphy, structure, and thickness of the Mesozoic rocks are based largely on interpretations of the records of approximately 200 oil test wells. The total volume of the Mesozoic rocks in Florida and southern Georgia is estimated at 60,000 to 75,000 cubic miles.

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CRETACEOUS SYSTEM

Gulf Series

Rocks of the Gulf series crop out in an irregular belt along the northern edge of the Coastal Plain in Georgia and occur in the subsurface throughout Florida and southern Georgia. Based mainly on lithologic criteria and characteristic microfaunal assemblages found in well samples, stratigraphic units of Navarro, Taylor, Austin, Eagle Ford, and Woodbine age are recognized in the subsurface Gulfian sequence. The Atkinson formation of Eagle Ford and Woodbine age (middle and early Upper Cretaceous) is recognized in deep wells in Florida and Georgia and is composed chiefly of clastic sediments. Except for the Atkinson formation, each stratigraphic unit in the Gulf series includes both a clastic and a nonclastic facies. In west Florida and most of south Georgia, a clastic facies, similar in its broader aspects to the sedimentary rocks of the western Gulf Coast, is mainly composed of shale and sand with some limestone and chalky marl. Over most of the Florida peninsula, the sedimentary section of the Gulf series is predominantly nonclastic chalky limestone and dolomite. The two facies merge laterally in southeast Georgia and the northern part of the peninsula (Fig. 1).

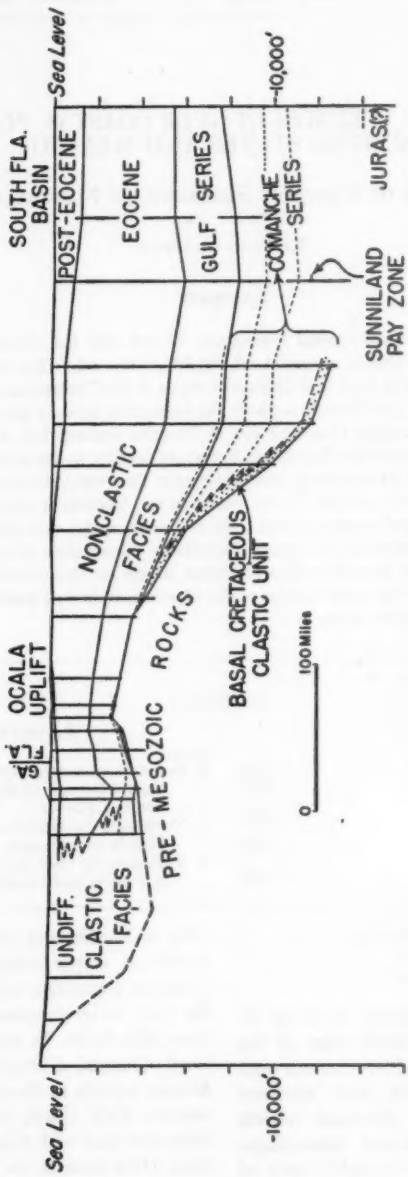


FIGURE 1.—GENERALIZED NORTH-SOUTH CROSS SECTION FROM OUTCROP OF CRYSTALLINE ROCKS IN CENTRAL GEORGIA TO BIG PINE KEY, MONROE COUNTY, FLORIDA

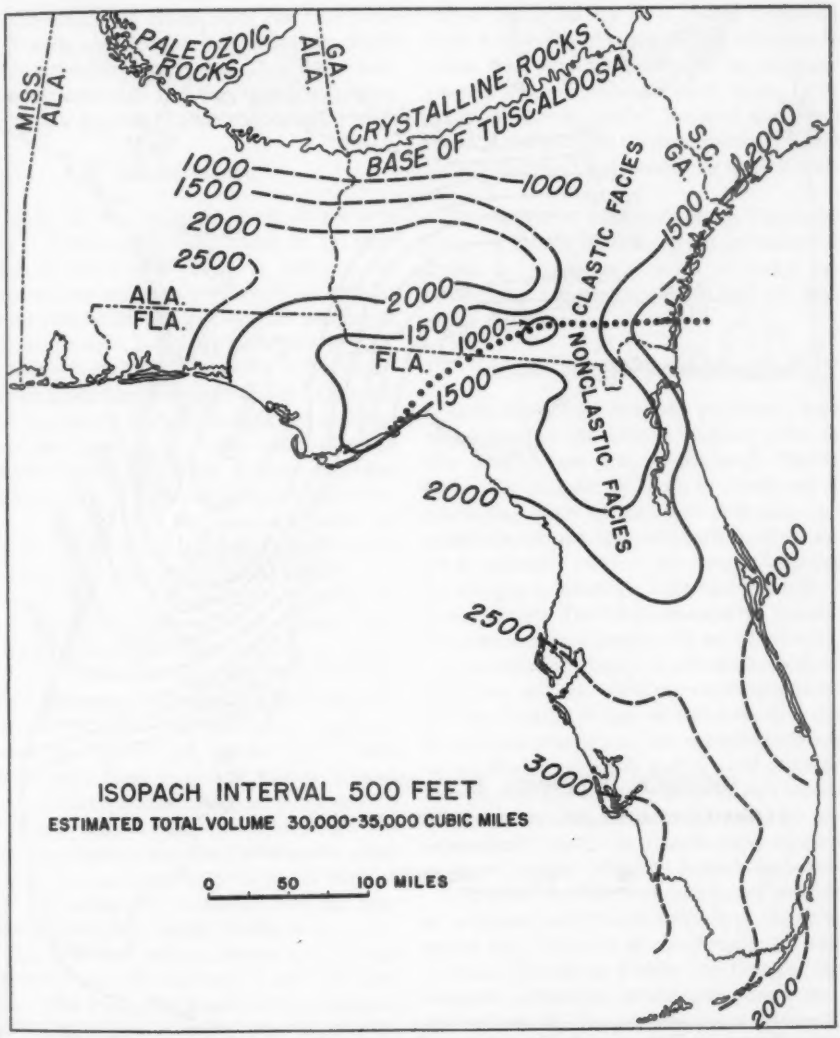


FIGURE 2.—VARIATIONS IN THICKNESS OF GULF SERIES IN FLORIDA AND GEORGIA

The formations of the Gulf series thicken southward from a wedge edge at the Fall Line in central Georgia to more than 2000 feet in the southwestern part of the State (Fig. 2); in the south Florida basin, the Gulf series attains a maximum thickness of approximately 3000 feet. Throughout an irregularly shaped area in northern Florida and southern Georgia, the Gulf series ranges from 1000 to 1500 feet in thickness. In a part of this area, the basal beds of the series are thin or absent; in another part, the topmost beds are absent.

The relative thinness of the Gulf series at the crest of the Ocala uplift in northern Florida is attributed chiefly to the gradual wedging out of the early and middle Upper Cretaceous Atkinson formation. In several wells drilled near the crest of the uplift, the Atkinson formation

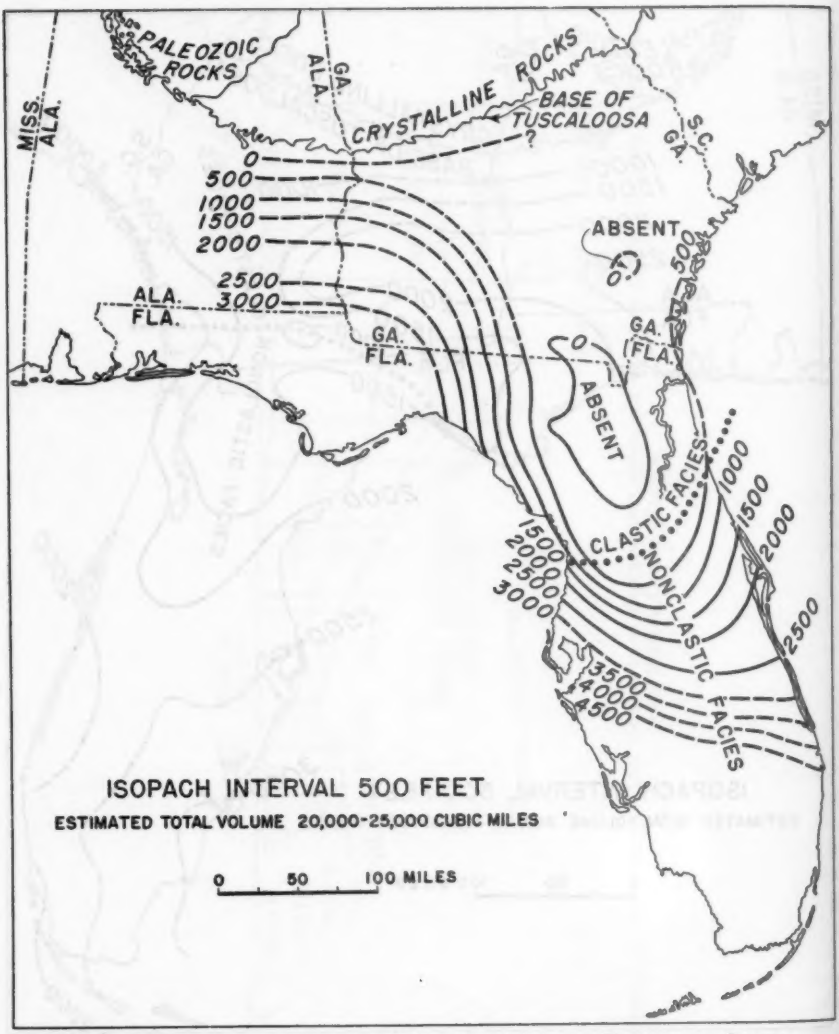


FIGURE 3.—VARIATIONS IN THICKNESS OF COMANCHE SERIES IN FLORIDA AND GEORGIA

is absent, and beds of Austin age rest directly on pre-Mesozoic rocks. In addition, the thickness of the Upper Cretaceous formations above the Atkinson is relatively less at the crest of the Ocala uplift than on the flanks.

Within the irregularly shaped area in northern Florida and southern Georgia, subsurface data show a channel at the top of the Upper Cretaceous rocks bordering the Ocala uplift on the north and northwest. The channel, which follows closely the zone of transition between facies, is probably partly structural and partly topographic in origin. In the area occupied by the channel, the late Upper Cretaceous beds of Navarro age and the upper part of the underlying beds of Taylor age were removed and the channel filled with Paleocene deposits.

The volume of sediments in the Gulf series in Florida and Georgia is estimated at 30,000 to 35,000 cubic miles. Nonclastic deposits compose approximately 17,500 to 20,000 cubic miles, and clastic deposits 12,500 to 15,000 cubic miles.

Comanche Series

Rocks of the Comanche series do not crop out in Florida or Georgia. South of the inner edge of the Coastal Plain in Georgia, the Comanchean rocks are overlapped by deposits of the Gulf series, but well data are insufficient for more than a rough approximation of their northern limits. The Comanche series occurs in the subsurface throughout most of Florida and the Coastal Plain of Georgia but is absent over the crest of the Ocala uplift in north Florida and in a limited area in southeast Georgia. Both a clastic and a nonclastic facies are recognized in the Comanche series in Florida. The nonclastic facies in south Florida is composed mainly of alternating beds of limestone, dolomite, and anhydrite. Microfaunas and lithologic studies of well samples have enabled geologists to differentiate the nonclastic rocks into units of Washita, Fredericksburg, and Trinity age, but the clastic deposits in other parts of Florida and in southern Georgia are largely undifferentiated. On the south flank of the Ocala uplift in central Florida, a basal unit composed, for the most part, of varicolored sandstone and siltstone interbedded with red and green shale rests on the pre-Mesozoic rocks. The unit ranges in age from Trinity to Washita and grades laterally southward into the nonclastic facies of the south Florida basin.

Relatively few wells in Florida and Georgia penetrated the full thickness of the Comanche rocks. The known thickness of the Comanche series ranges from a wedge edge up to 4500 feet (Fig. 3). A greater thickness can be postulated for the Comanche series in the south Florida basin and in west Florida. In a well on Big Pine Key, Monroe County, Florida, the Comanche series is at least 6250 feet thick; in west Florida, a well in Jackson County penetrated approximately 5000 feet of Comanche beds. A relatively thin section of the Comanche series was penetrated by wells in southeast Georgia and on the north flank of the Ocala uplift in Florida, but on the west and south flanks of the uplift the Comanche series thickens rapidly Gulfward and toward the south Florida basin.

The volume of sediments of the Comanche series in Florida and Georgia is estimated at 20,000 to 25,000 cubic miles, of which approximately half are clastic and half are nonclastic deposits.

Jurassic and Triassic Systems

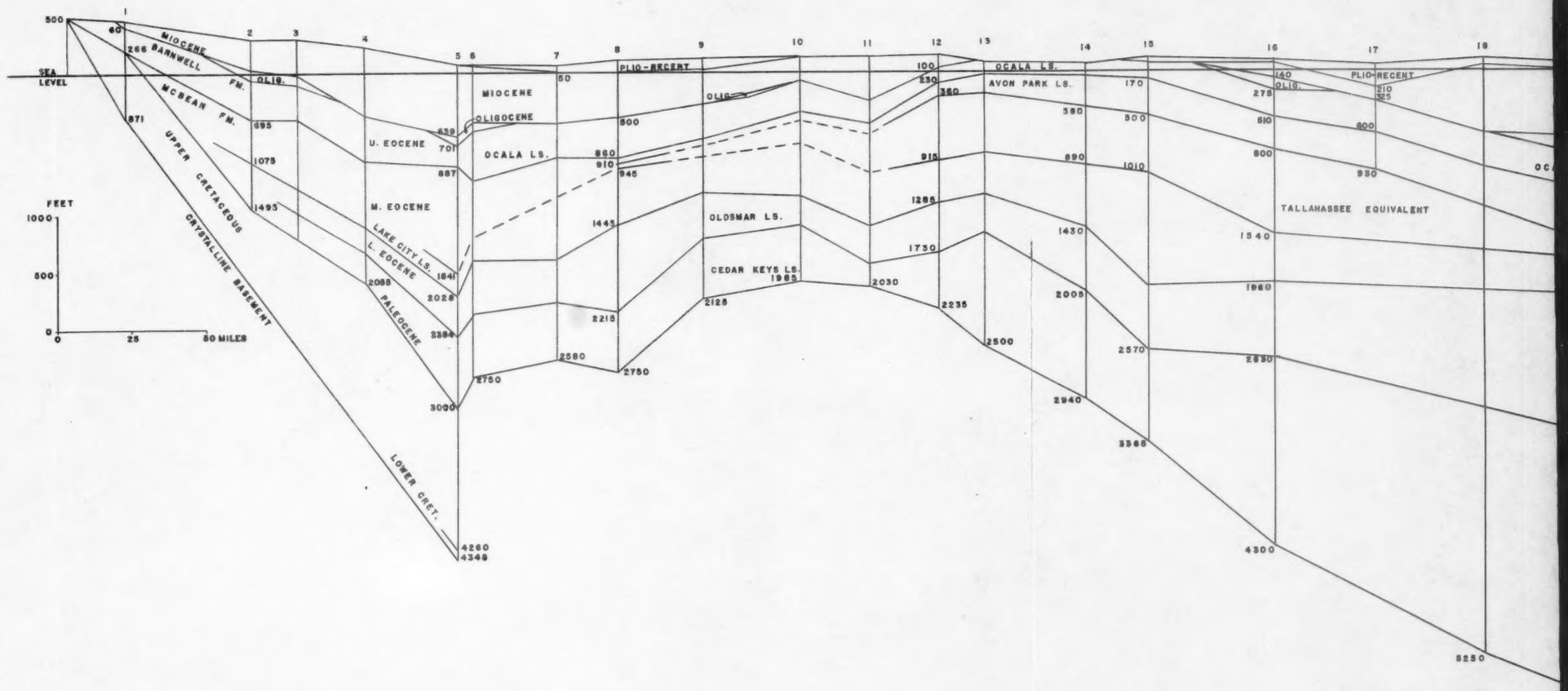
Rocks tentatively classified as Jurassic were encountered in the bottom parts of three or four deep oil-test wells in the south Florida basin. The Jurassic (?) rocks are composed of alternating layers of limestone, dolomite, and anhydride and are differentiated from the overlying nonclastic rocks of the Comanche series by changes in lithologic character and microfaunal content. The full thickness of the Jurassic (?) rocks was not penetrated in any of the wells.

A sequence of red and green shale interbedded with gray and red sandstone containing flows and intrusions of diabase underlies clastic rocks of the Comanche series in the northwest portion of the Florida peninsula and in parts of south Georgia, and is tentatively classified as Triassic. These sedimentary rocks and the diabase are lithologically similar to Triassic rocks exposed at many localities along the Atlantic seaboard.

The data from scattered tests do not provide an adequate basis for an estimate of the areal extent and thickness of the Jurassic (?) and Triassic (?) rocks in Florida and Georgia. Incomplete subsurface information shows that the volume of the pre-Cretaceous Mesozoic rocks is roughly estimated at 10,000 to 15,000 cubic miles.

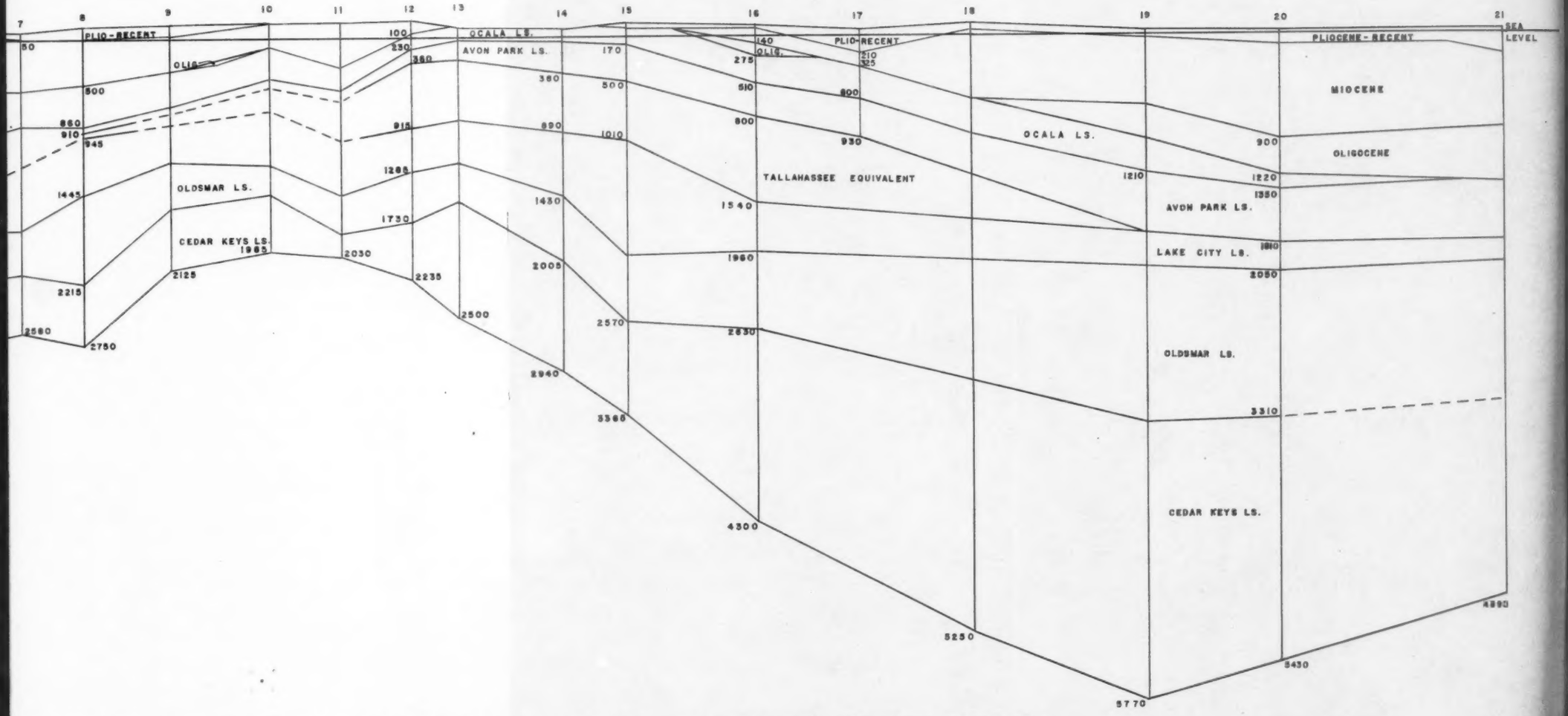
U. S. Geological Survey, Jackson, Miss.
Manuscript Received by the Secretary of the Society, May 22, 1951
Published by Permission of the Director, U. S. Geological Survey

1. Sandersville Public Water Well 51, Washington County, Georgia (La Mareaux, 1946, p. 121).
2. Glen Rose, Fowler No. 1, Treutlen County, Georgia (Richards, 1945, p. 923).
3. Weatherford, Wilkes No. 1, Montgomery County, Georgia.
4. Felsenthal, W. Bradley No. 1, Appling County, Georgia.
5. W. B. Hinton (Clark), Adams Mc Caskill No. 1, Pierce County, Georgia (Applin and Applin, 1944, p. 1744).
6. Pan Am., Adams Mc Caskill No. 1, Pierce County, Georgia.
7. California, John A. Buie No. 1, Camden County, Georgia.
8. St. Marys River Oil Corp., Hilliard No. 1, Nassau County Florida (Cole, 1944; Applin and Applin, 1944, p. 1734).
9. Hunt Oil Co., Hunt No. 1, Baker County, Florida.
10. Tide Water Associated Oil Co., M. F. Wiggins No. 1, Bradford County, Florida.
11. Tide Water Associated Oil Co., J. A. Phifer No. 1, Alachua County, Florida.
12. J. S. Cosden, Inc., W. L. Lawson No. 1, Marion County Florida (Applin and Applin, 1944, p. 1739).
13. Ocala Oil Corp., York No. 1, Marion County, Florida.
14. Dundee Petroleum Co., "Bushnell well," Sumter County, Florida (Applin and Applin, 1944, p. 1734).
15. Oil Development Co. of Florida, South Lake No. 2, Lake County, Florida (Applin and Applin, 1944, p. 1734).
16. Pioneer Oil Co., Hecksher-Yarnell No. 1, Polk County, Florida (Applin and Applin, 1944, p. 1735).
17. Avon Park Bombing Range Water Well, Polk County, Florida (Applin and Applin, 1944, p. 1740).
18. Humble Oil and Refining Co., C. C. Carlton Est. No. 1, Highlands County, Florida.
19. Humble Oil and Refining Co., Gulf Coast Realties No. 1, Collier County, Florida.
20. Peninsular Oil and Refining Co., J. W. Cory No. 1, Monroe County, Florida (Cole, 1941; Applin and Applin, 1944, p. 1735).
21. Gulf Oil Corp., State of Florida J. P. Scranton No. 1, Monroe County, Florida.



CROSS SECTION FROM HANCOCK COUNTY, GEORGIA, TO MONROE COUNTY, FLORIDA

See Figure 1 for location of section



CROSS SECTION FROM HANCOCK COUNTY, GEORGIA, TO MONROE COUNTY, FLORIDA

See Figure 1 for location of section

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VOL. 63, PP. 1165–1176, 8 FIGS., 1 PL. DECEMBER 1952

SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF THE UNITED STATES AND MEXICO

PART II: VOLUME OF CENOZOIC SEDIMENTS IN FLORIDA AND GEORGIA

BY LYMAN D. TOULMIN

ABSTRACT

Cenozoic sediments having a maximum thickness of 3000 feet and an average thickness of 1500 feet underlie an area of 33,000 square miles in southern Georgia. The thickness increases at a rather regular rate from the northern edge of the outcrop area southeastward. The total volume of Cenozoic sediments in Georgia is 9500 cubic miles.

Cenozoic sediments underlie all of Florida, an area of 58,560 square miles. During the Cenozoic there were two chief basins of deposition. The one, centered west of northwestern Florida and extending into the western edge of the State, contains chiefly clastic deposits. The other, in the southern part of the peninsula, contains carbonate rocks with some gypsum and anhydrite. Cenozoic sediments are thinnest near the north-central part of the peninsula. The total volume of Cenozoic sediments in Florida is 40,000–41,000 cubic miles.

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INTRODUCTION

The well data used in preparing the isopach maps in the volume calculations were gathered from Florida Geological Survey publications (Cole, 1938; 1941; 1942; 1944; 1945; Parker and Cooke, 1944) and other publications (Applin and Applin, 1944; Cooke, 1943; La Moreaux, 1946; Prettyman and Cave, 1923; Richards, 1945) and from the unrestricted well log files and well sample library of the Florida Geological Survey. Additional data were contributed by geologists who have studied deep wells in this area.

Altogether, data on 194 wells in Florida and 52 wells in Georgia were used, but, needless to say, information on the thickness of each unit of the Cenozoic was not available from every well. For example, the isopach map of the Paleocene series (Fig. 2) is based on information from only 35 deep wells in Florida and 17 in Georgia. Information is available from many more wells for each of the younger units of the Cenozoic, however. The isopach map showing the thickness of the whole Cenozoic (Fig. 1) is based on data from 108 deep wells in Florida and 32 in Georgia. Petroleum geologists work-

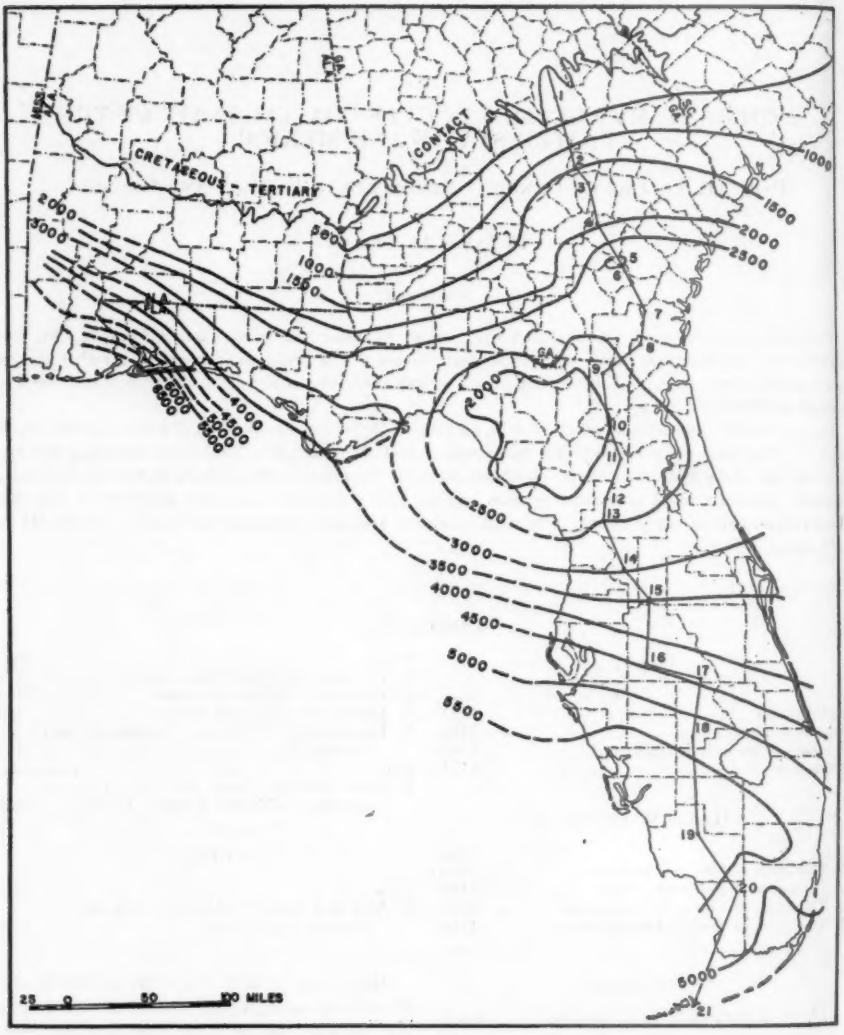


FIGURE 1.—THICKNESS OF CENOZOIC SEDIMENTS
Isopach interval, 500 feet. Location of cross section through wells numbered 1 to 21. (*See* Plate 1.)

ing in this area have been more interested in the Upper Cretaceous and older rocks and have given comparatively little attention to the Cenozoic units.

ACKNOWLEDGMENTS

The writer is deeply indebted to Mr. Paul Applin and Mrs. Esther Applin of the United States Geological Survey who kindly furnished data on depths to the top of the Upper Cretaceous in many wells in Georgia and Florida, and to Mr. E. H. Rainwater of the Shell Oil Company who supplied information on thicknesses of the Cenozoic divisions in a large number of wells.

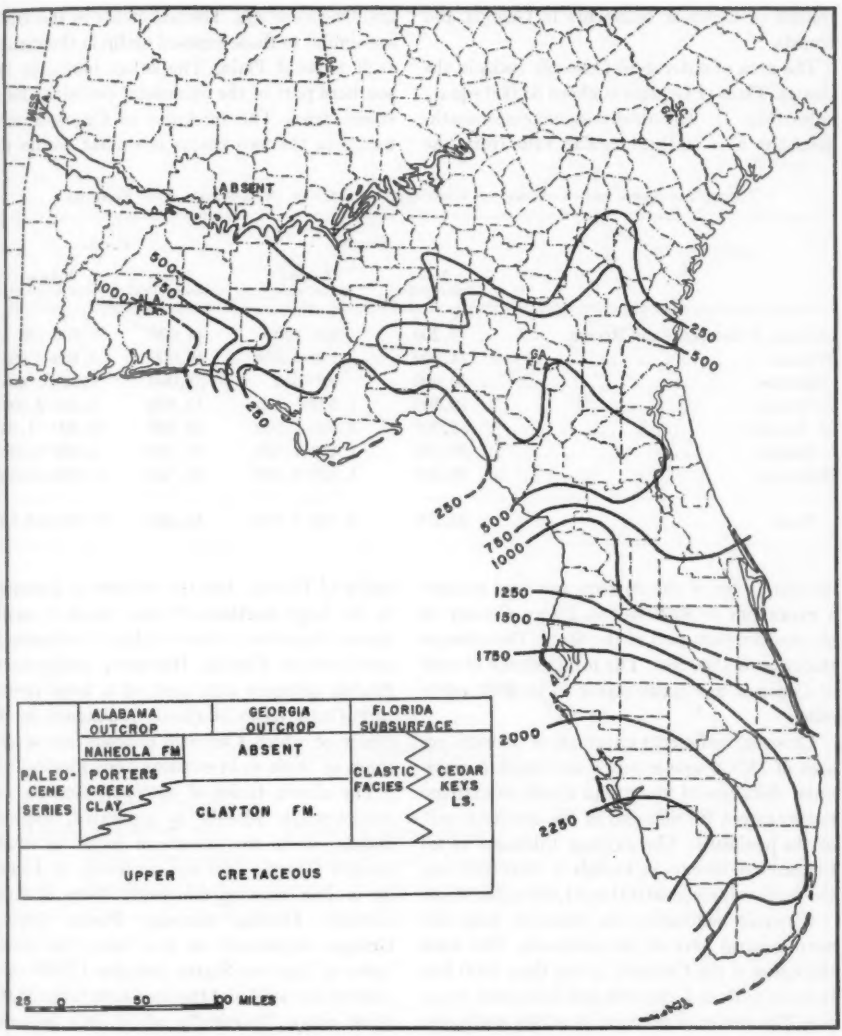


FIGURE 2.—THICKNESS OF PALEOCENE SERIES
Isopach interval, 250 feet.

VOLUME OF CENOZOIC SEDIMENTS

Cenozoic sediments underlie all of Florida and southern Georgia, an area of about 91,000 square miles, and rest on sedimentary rocks of the Gulf (Upper Cretaceous) series, except in a few places along the Fall Line in eastern Georgia where Eocene rocks lap over the Cretaceous and rest on crystalline rocks. The total volume of Cenozoic sediments in the two States is 50,000 cubic miles, an average of a little more than half a cubic mile of sedimentary rock per square mile of area. No information is available on which to base estimates of thickness and volume of Cenozoic sediments in the continental shelf. Table 1 gives area and

volume of Cenozoic sediments in Georgia and Florida.

The area of outcrop of Cenozoic rocks in the Coastal Plain of Georgia is about 33,000 square miles (Fig. 1). The thickness increases southeastward at a rather regular rate from the northern edge of the outcrop area and reaches a maximum of 3000 feet in Pierce County in the southeastern part of the State. The average thickness is 1500 feet. The total volume of rock of Cenozoic age is calculated to be 9500 cubic miles.

Cenozoic sediments cover all of Florida, an area of 58,560 square miles, and reach a maximum thickness of more than a mile in extreme northwestern Florida and in the southern part of the peninsula. The average thickness of all Cenozoic sediments in Florida is 3600 feet, and the total volume is 40,000 to 41,000 cubic miles.

Cenozoic sediments are thinnest near the north-central part of the peninsula. The total thickness of the Cenozoic is less than 1600 feet in some wells in Lafayette and Suwannee counties. The center of this area is at the northwest edge of the area of outcrop of the Ocala limestone (upper Eocene) and about 55 miles northwest of the center of the area of outcrop. This prominent structural feature has been called the Ocala uplift, although it does not coincide exactly with the outcrop of the Ocala limestone.

There are two chief Cenozoic sedimentary basins in Florida. One, centered west of northwestern Florida and extending into the western part of the State, contains clastic sediments with a few thin limestone beds of late Eocene and Oligocene age. The sediments in this basin are similar to those exposed updip in the eastern Gulf Coastal Plain. The other basin, in the southern part of the peninsula, contains a limestone facies. The thickness of Cenozoic sediments in the two basins is similar within the limits of Florida, but the volume of limestone in the large southern Florida basin is vastly greater than the volume of clastic sediments in northwestern Florida. However, northwestern Florida occupies only part of a large central Gulf Coast basin of clastic sediments, in the center of which Cenozoic deposits are several times as thick as in northwestern Florida.

TABLE 1.—AREA AND VOLUME OF CENOZOIC SEDIMENTS IN GEORGIA AND FLORIDA

	Georgia		Florida	
	Area (square miles)	Volume (cubic miles)	Area (square miles)	Volume (cubic miles)
Pliocene, Pleistocene and Recent	9,200	100–120	44,000	500–550
Miocene	24,000	1,100–1,300	46,000	3,600–3,700
Oligocene	20,000	600–630	31,000	1,500–1,600
U. Eocene	29,500	1,600–1,700	55,500	2,200–2,800
M. Eocene	32,000	3,000–3,200	58,560	10,500–11,500
L. Eocene	30,000	1,400–1,500	58,560	8,600–9,000
Paleocene	29,000	1,300–1,400	58,560	12,000–13,000
Total	33,000	9,100–9,850	58,560	38,900–42,150

The clastic facies of southern Georgia and northwestern Florida is separated, approximately, from the limestone facies of southeastern Georgia and the peninsula of Florida by a line running northeast from Wakulla County, Florida, through Pierce County, Georgia. Separated on this basis, the clastic facies of the two States includes 12,000 cubic miles of material and the limestone facies 38,000 cubic miles. Practically all of this material, including the clastic, is of marine origin.

The area of maximum thickness of the Paleocene series in Georgia is in the south and southeast (Fig. 2). The areas of maximum thickness in Florida are in the south and in the northwest. The clastic sediments of Paleocene age in northwestern Florida consist chiefly of gray clay, sandy clay, and greenish-gray fossiliferous marl. The Cedar Keys limestone, present in the peninsula, is gray to white with considerable gypsum and some anhydrite. White

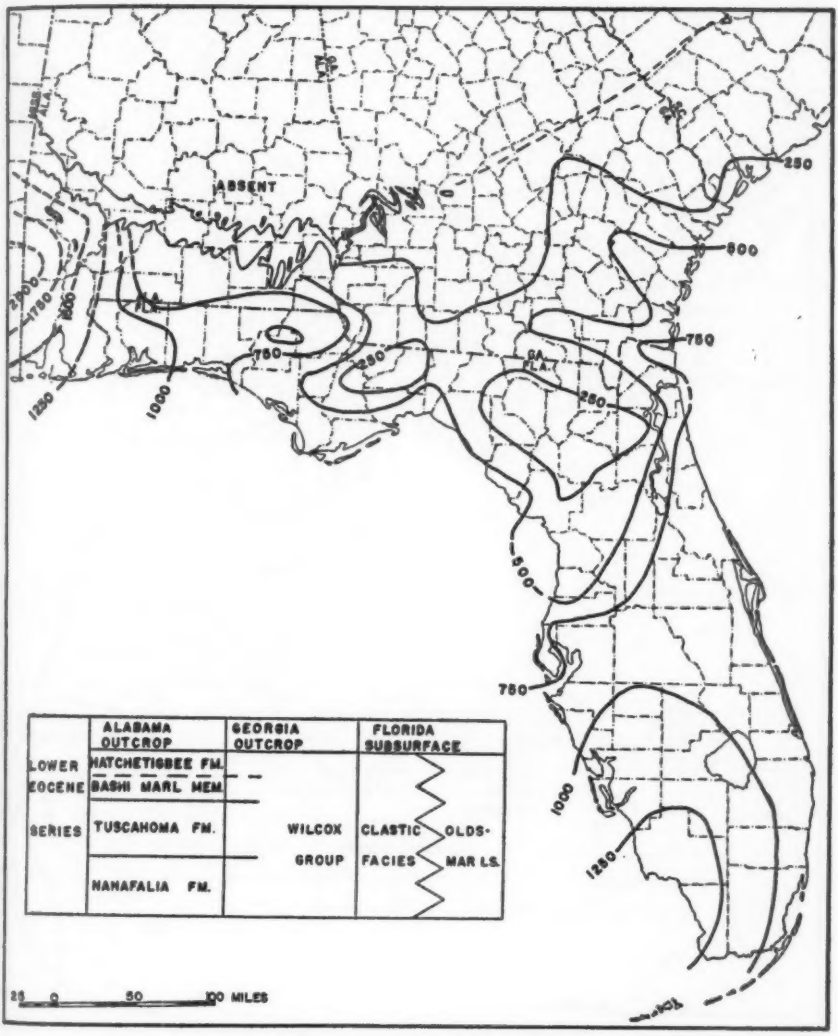


FIGURE 3.—THICKNESS OF LOWER EOCENE SERIES
Isopach interval, 250 feet.

limestone (Clayton formation) is exposed on the Chattahoochee River in western Georgia. The volume of Paleocene rock in the two States is about 13,500 cubic miles.

The areas of maximum thickness of the Lower Eocene series are in southeastern Georgia, southern Florida, and northwestern Florida (Fig. 3). The area of minimum thickness in Florida is in the northern part of the peninsula. The clastic sediments of Lower Eocene age in northwestern Florida consist chiefly of gray and greenish-gray micaceous sandy clay and sand. The Salt Mountain limestone, present in part of the area, makes up the lower part of the unit. The Oldsmar limestone, constituting the Lower Eocene unit in the peninsula, con-

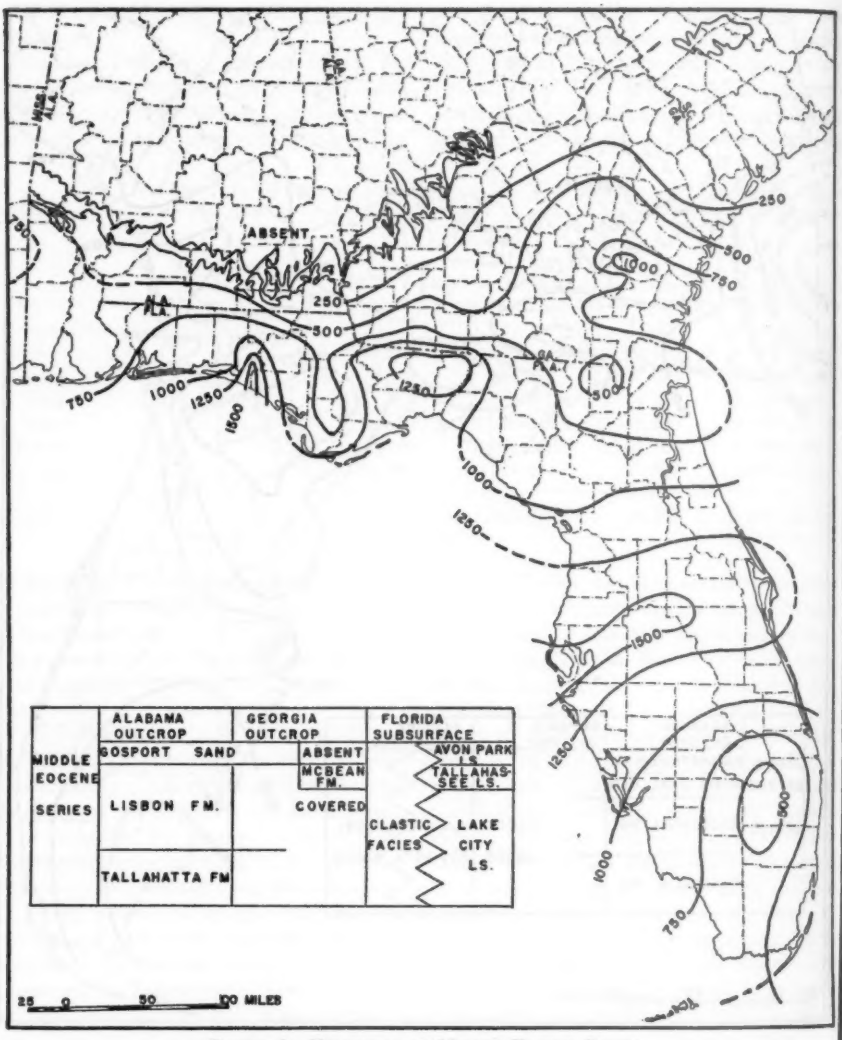


FIGURE 4.—THICKNESS OF MIDDLE EOCENE SERIES
Isopach interval, 250 feet.

tains some gypsum. The volume of Lower Eocene rock in the two States is about 10,500 cubic miles.

The areas of maximum thickness of the Middle Eocene series are in southeastern Georgia, the central part of the Florida peninsula, and in the Bay County area of northwestern Florida (Fig. 4). The Middle Eocene series in northwestern Florida consists of glauconitic sand, claystone, and sandy glauconitic marl. East of the Apalachicola River this series includes, from bottom up, the Lake City limestone, consisting of alternating layers of dark-brown and chalky limestone; the Tallahassee limestone and an equivalent non-fossiliferous limestone, consisting of tan to

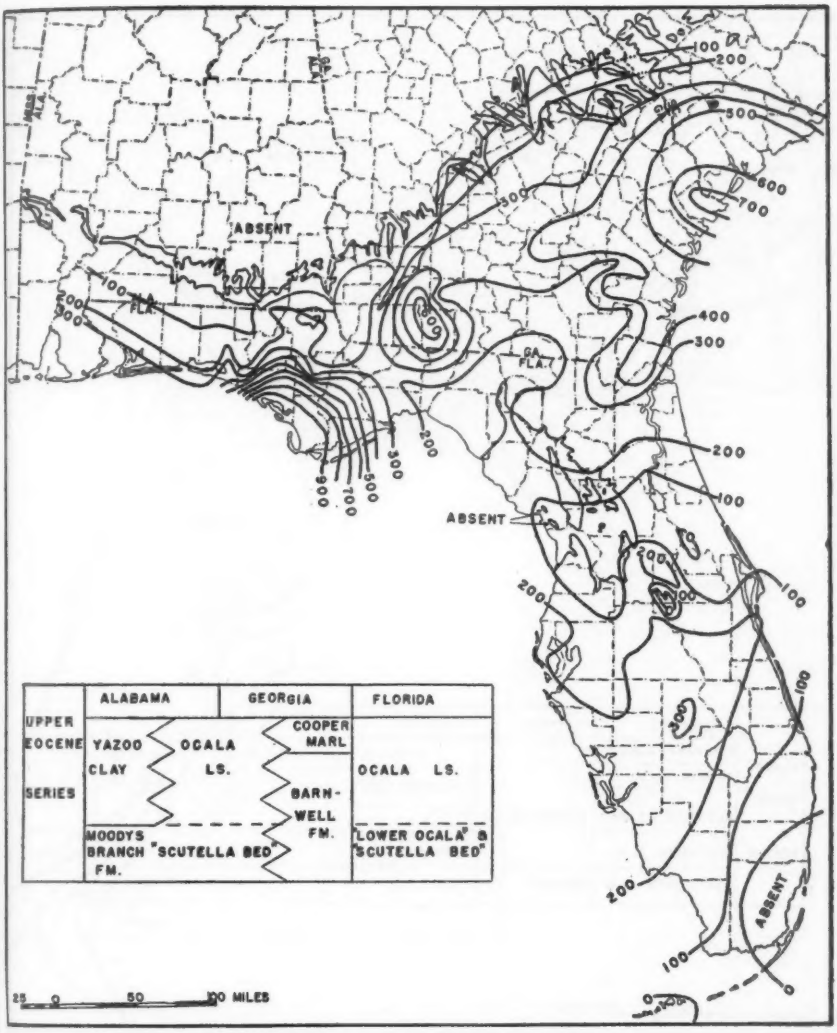
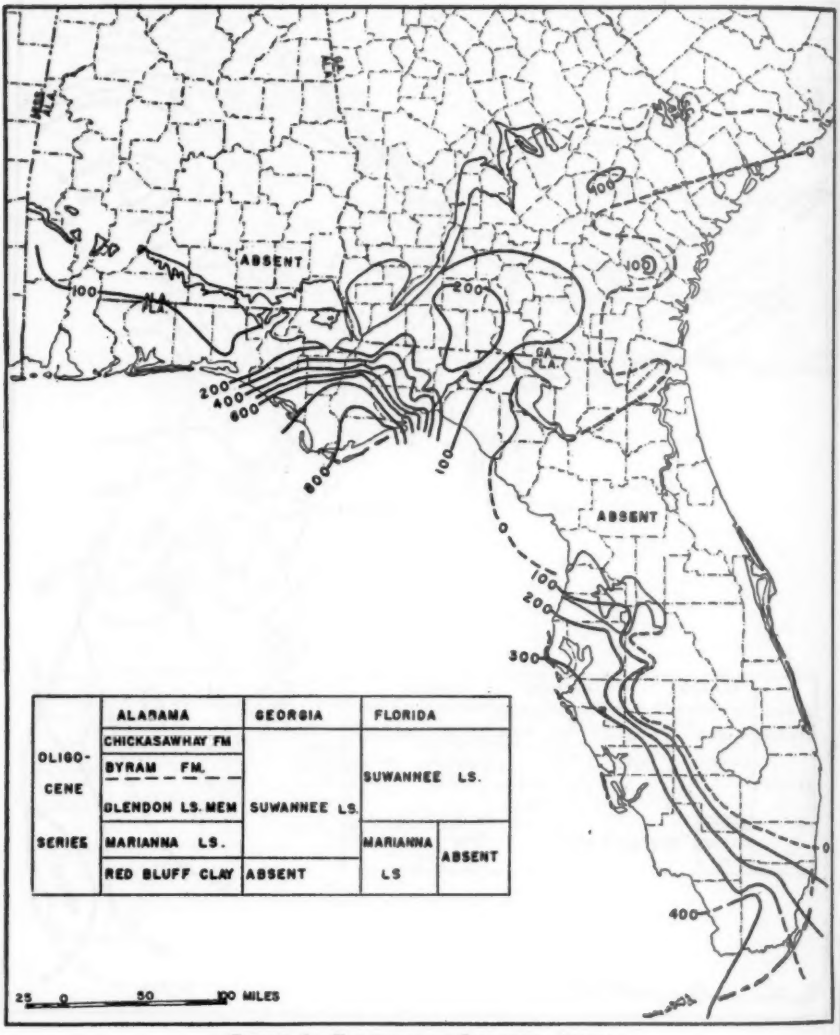


FIGURE 5.—THICKNESS OF UPPER EOCENE SERIES
Isopach interval, 100 feet.

white crystalline limestone and argillaceous limestone with some gypsum and chert, and with thin streaks of carbonaceous clay in central Florida; and the Avon Park limestone, consisting of cream-colored highly fossiliferous chalky limestone (Applin and Applin, 1944). The Avon Park limestone of late Middle Eocene age crops out in small areas in Levy County and is the oldest exposed rock in Florida. The volume of Middle Eocene rock in the two States is about 14,000 cubic miles.

The Upper Eocene series consists of clastic sediments, chiefly sand, in east-central Georgia (Barnwell formation) and soft granular fossiliferous limestone of equivalent age in southern Georgia and throughout Florida (Ocala lime-



	ALABAMA	GEORGIA	FLORIDA	
OLIGOCENE SERIES	CHICKASAWHAY FM	SUWANNEE LS.	SUWANNEE LS.	
	BYRAM FM.			
	GLENDON LS. MEM			
	MARIANNA LS.		MARIANNA LS	ABSENT
	RED BLUFF CLAY	ABSENT		

FIGURE 6.—THICKNESS OF OLIGOCENE SERIES
Isopach interval, 100 feet.

stone). The maximum thickness is in the Apalachicola area (Fig. 5). The Ocala limestone is absent in small areas in the central part of the peninsula and in the area around Miami and Key West. The volume of Upper Eocene rock in the two States is about 4400 cubic miles.

The Oligocene series consists of white finely porous limestone in both Georgia and Florida. The maximum thickness is in the Apalachicola area (Fig. 6). It is absent near the coast in eastern Georgia and over a large area in the eastern and north-central part of the peninsula of Florida. The volume of Oligocene rock in both States is about 2100 cubic miles.

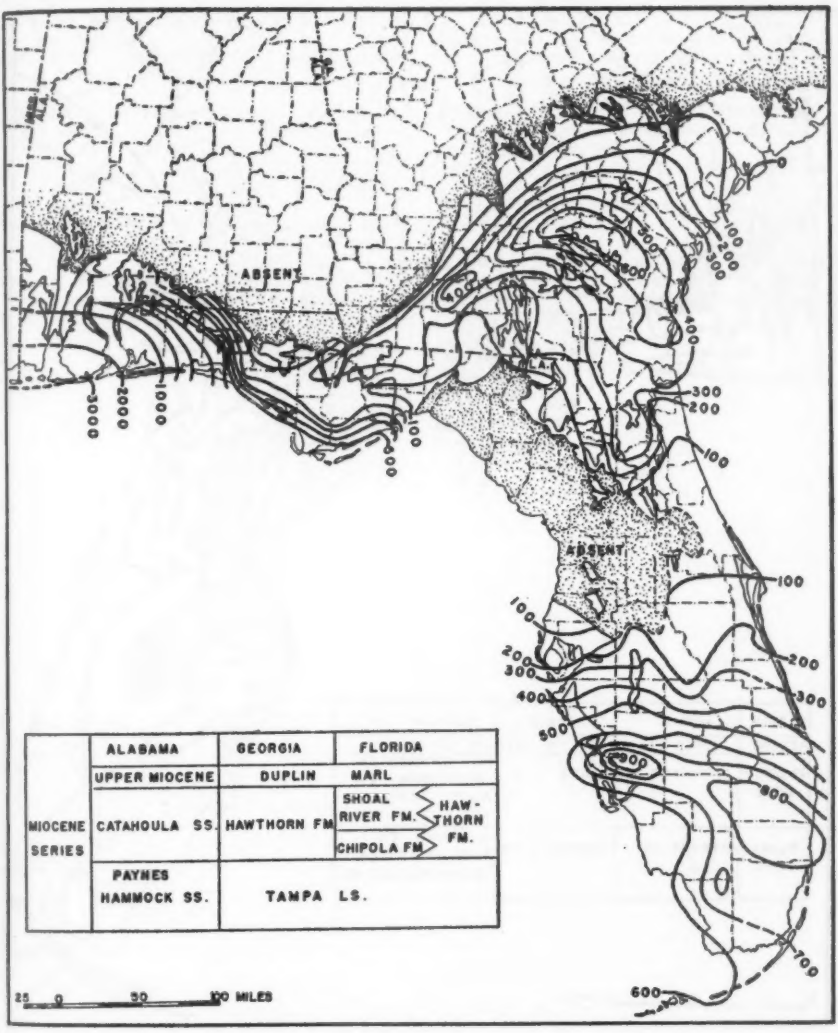


FIGURE 7.—THICKNESS OF MIOCENE SERIES
Isopach interval, 100 feet, except in northwest Florida.

The Miocene series consists chiefly of clastic deposits, sand, clay, shell marl, and some limestone, in western Florida and Georgia and phosphatic limestone in the peninsula of Florida. The areas of maximum thickness are central southeastern Georgia, western Florida, and southern Florida (Fig. 7). The volume of Miocene rock in both States is about 4900 cubic miles.

Pliocene, Pleistocene, and Recent deposits occupy a wide area along the east coast of Georgia and Florida and cover all of southern Florida and much of northwestern Florida. The maximum thickness is near the central part of

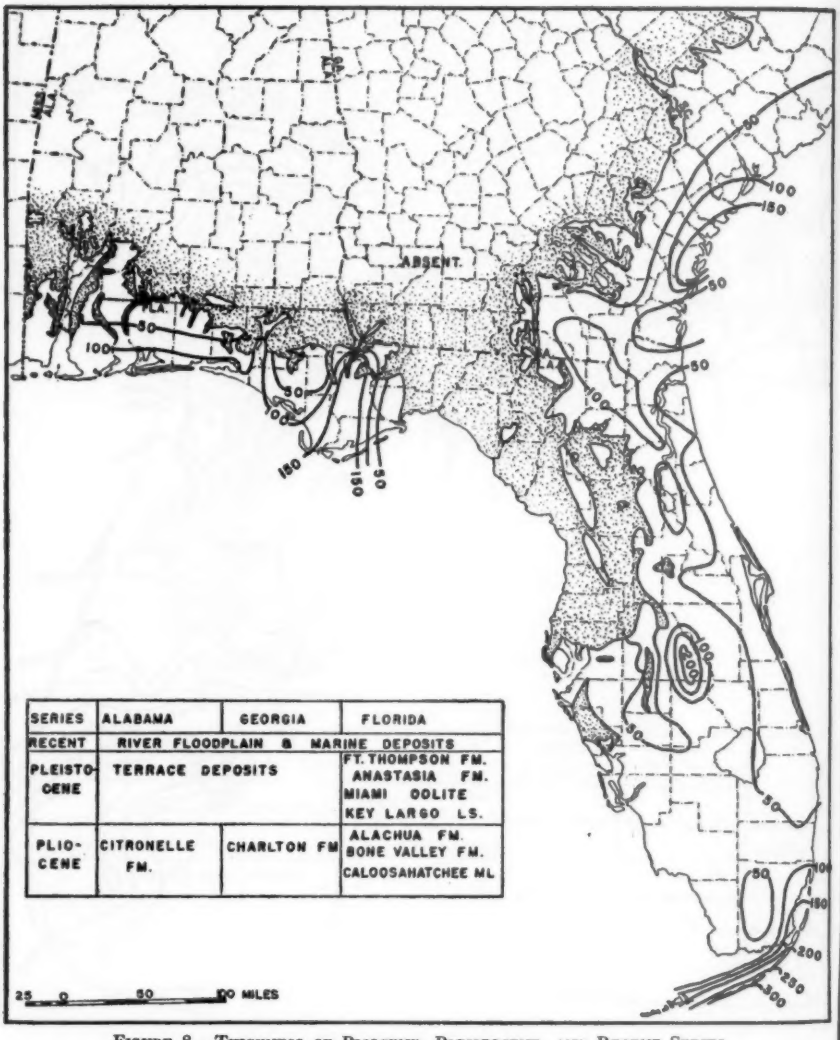


FIGURE 8.—THICKNESS OF PLIOCENE, PLEISTOCENE, AND RECENT SERIES
Isopach interval, 50 feet.

the peninsula and in the Florida Keys (Fig. 8). Except in southern Florida the sediments are clastic. The volume of sediment deposited during these epochs in both States is about 640 cubic miles.

The diagrammatic cross section shows the comparative thicknesses and relationships of the Cenozoic formations from the Fall Line in Hancock County, Georgia, to the Florida Keys (Pl. 1).

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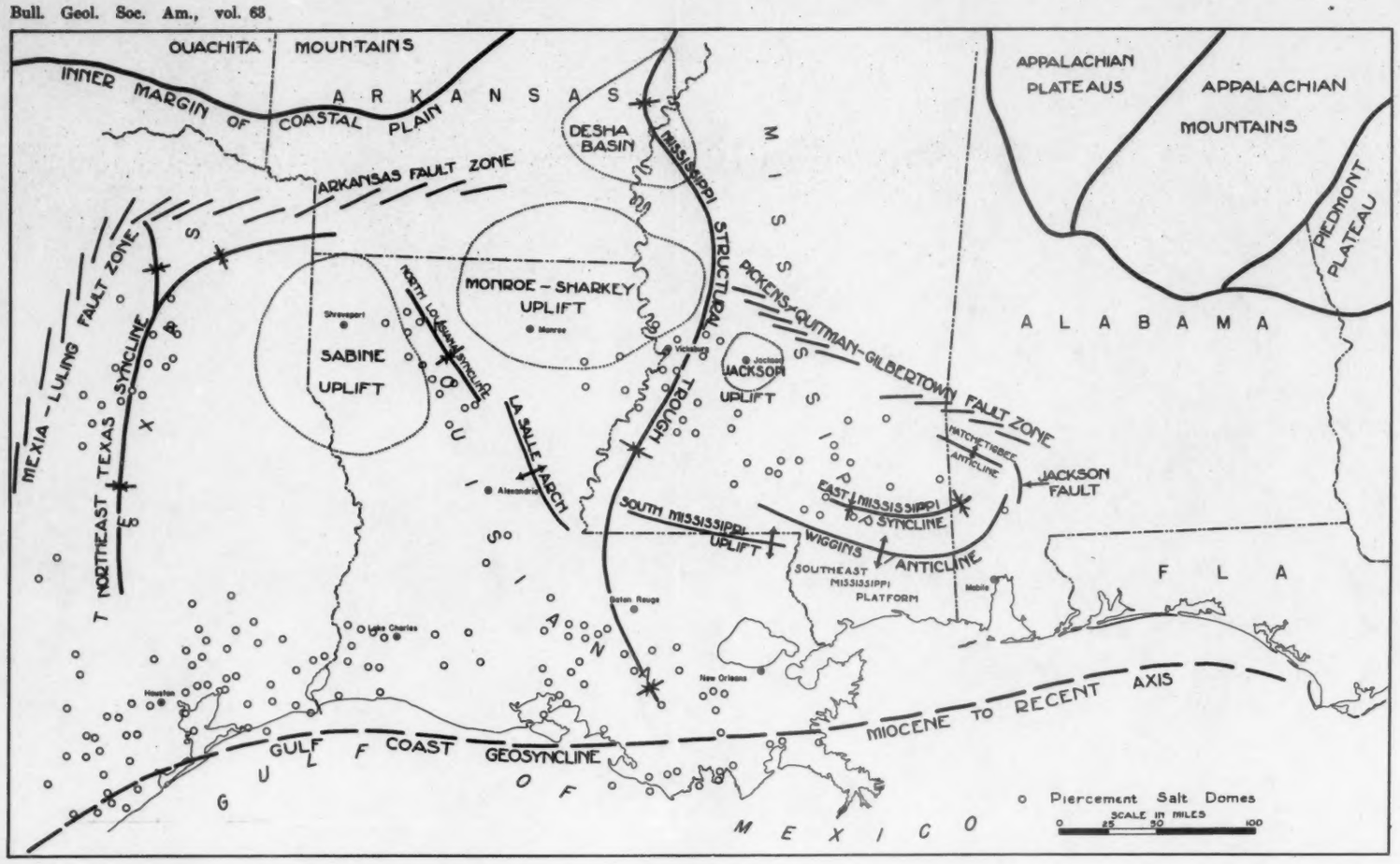

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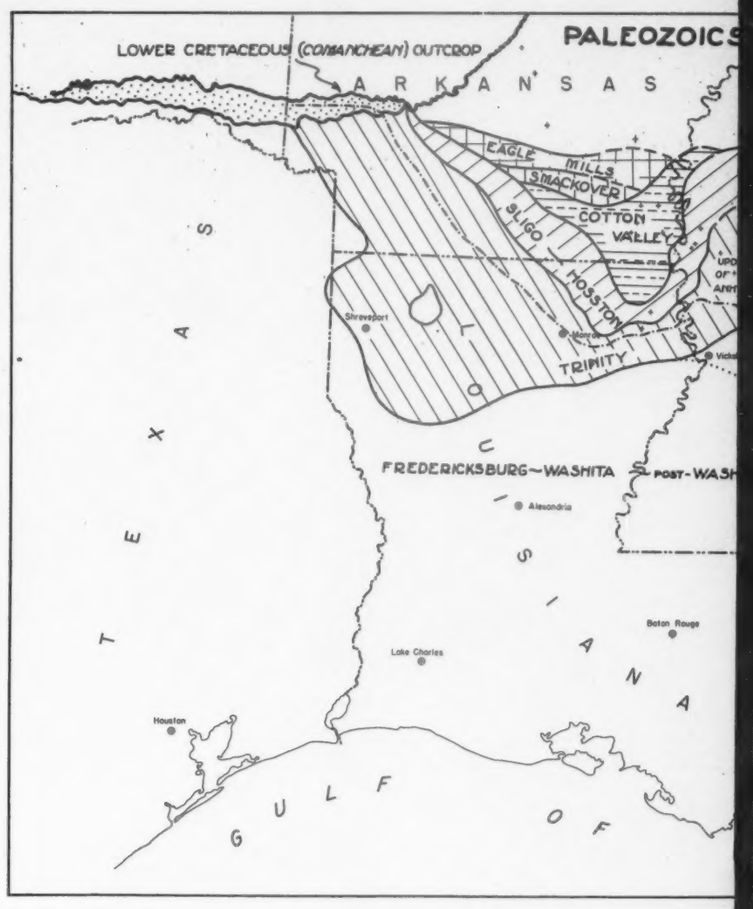

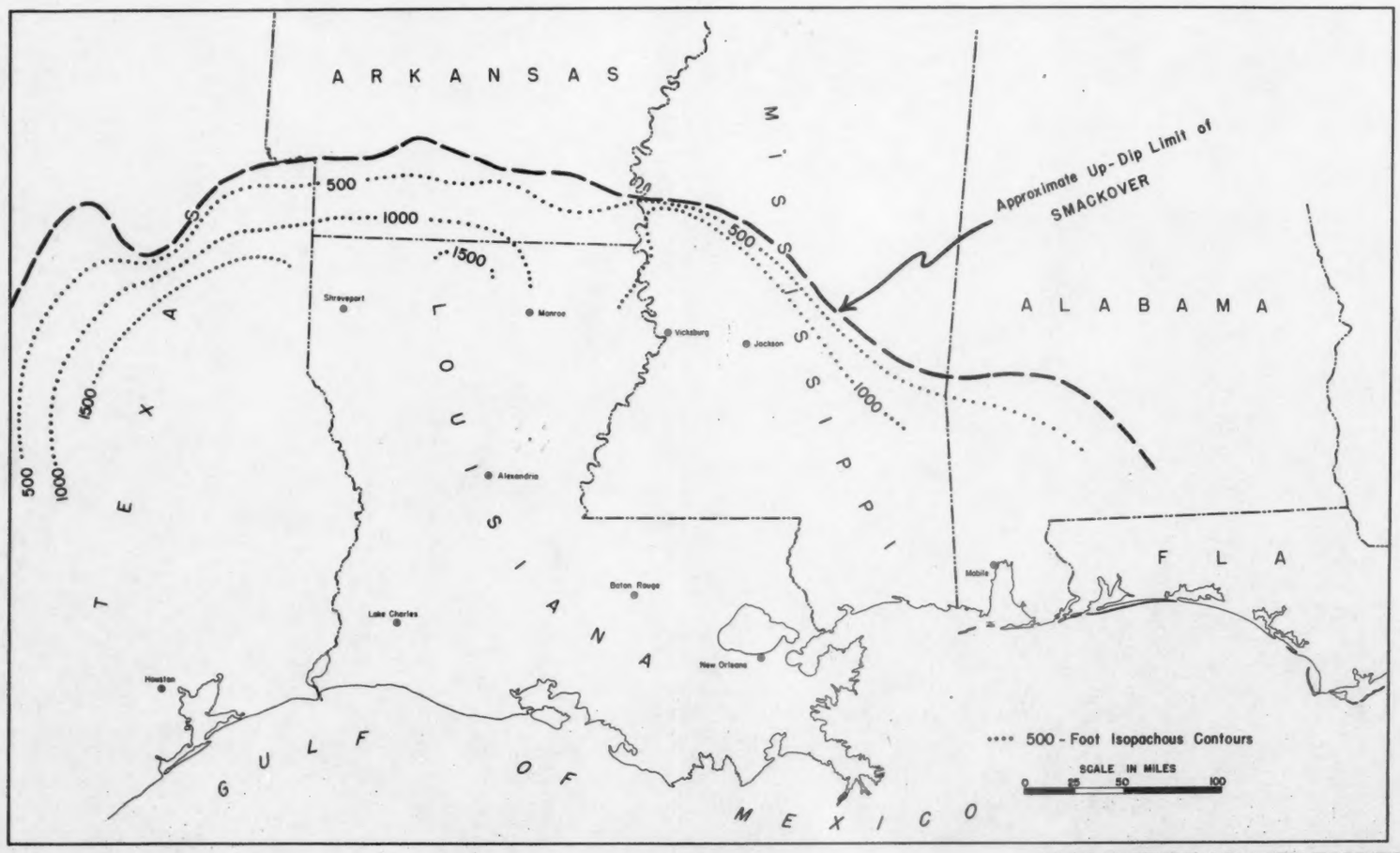

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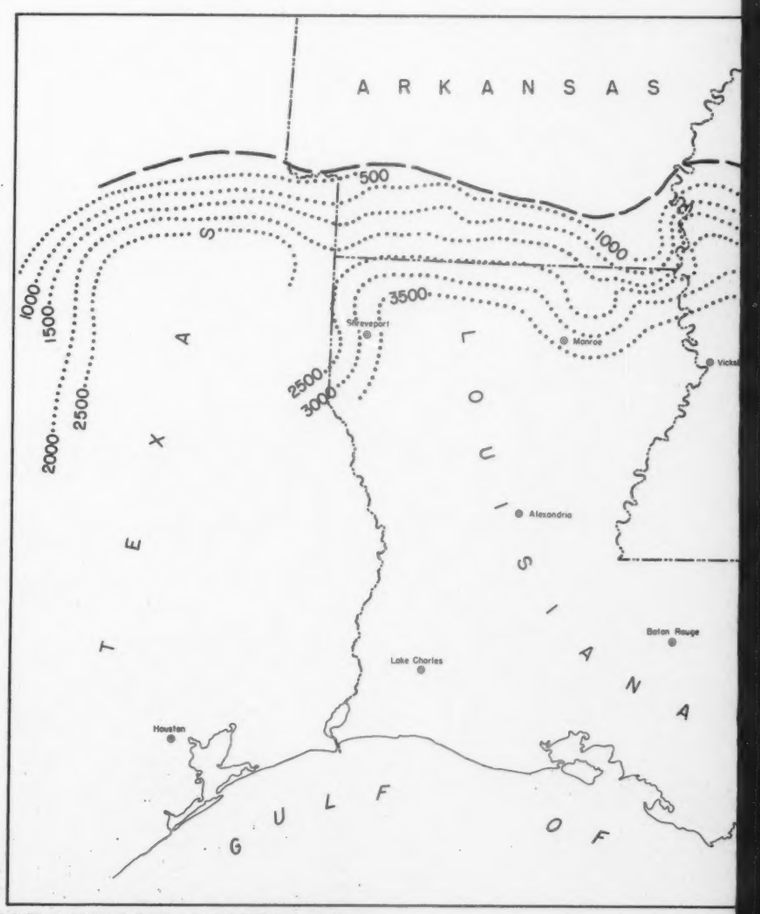


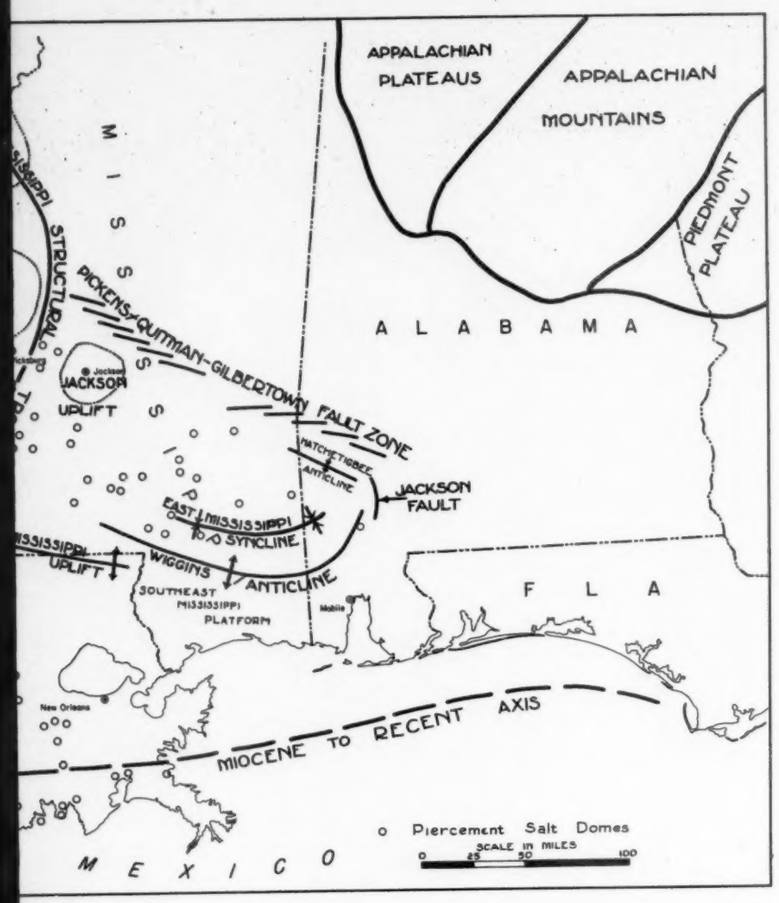
STRUCTURAL FEATURES AND ISOPACHOUS CONTOURS

A. STRUCTURAL FEATURES, CENTRAL GULF COASTAL PLAIN

B. GENERALIZED DISTRIBUTION OF PRE-UPPER CRETACEOUS (GULF SERIES) SEDIMENTS, CENTRAL GULF COASTAL PLAIN (NORTHWEST LOUISIANA AND SOUTHWEST ARKANSAS MODIFIED AFTER FISHER, KIRKLAND, AND BURROUGHS, 1949)

C. ISOPACHOUS CONTOURS OF UPPER JURASSIC (SMACKOVER FORMATION; HAYNESVILLE, IN PART)

D. ISOPACHOUS CONTOURS OF UPPER JURASSIC (COTTON VALLEY GROUP; HAYNESVILLE, IN PART)



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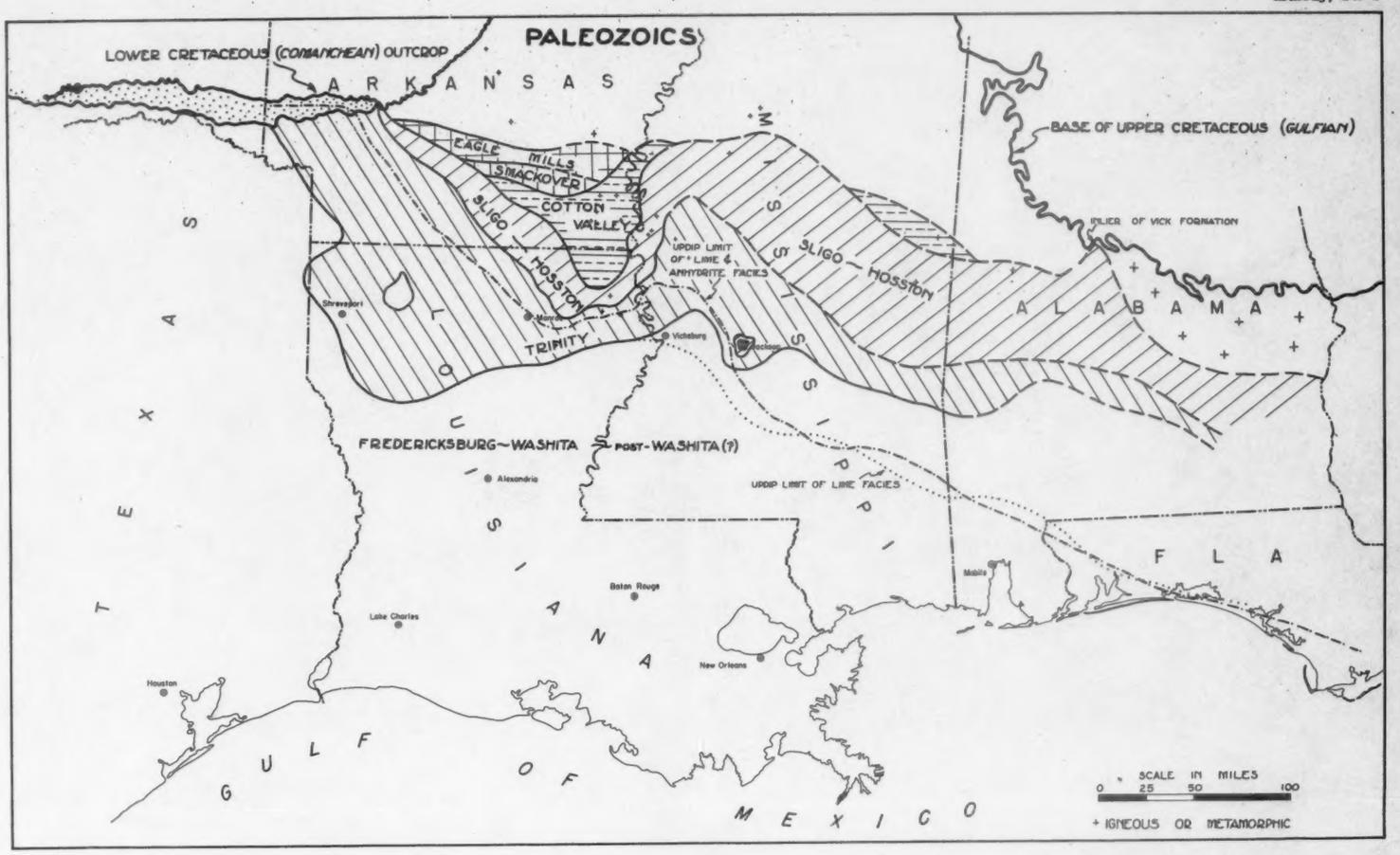

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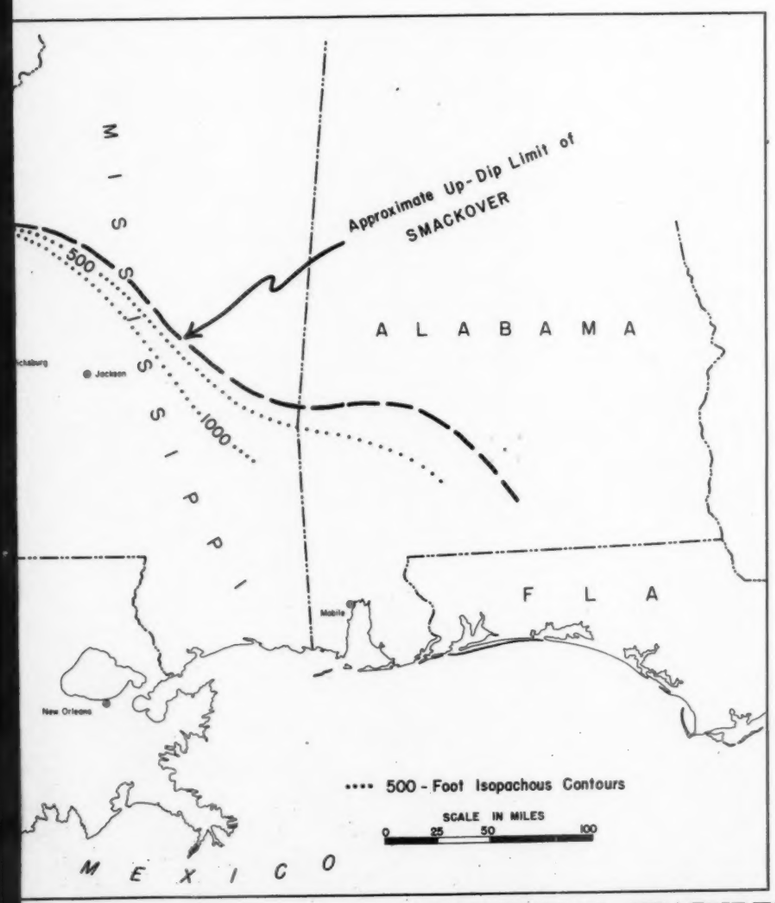

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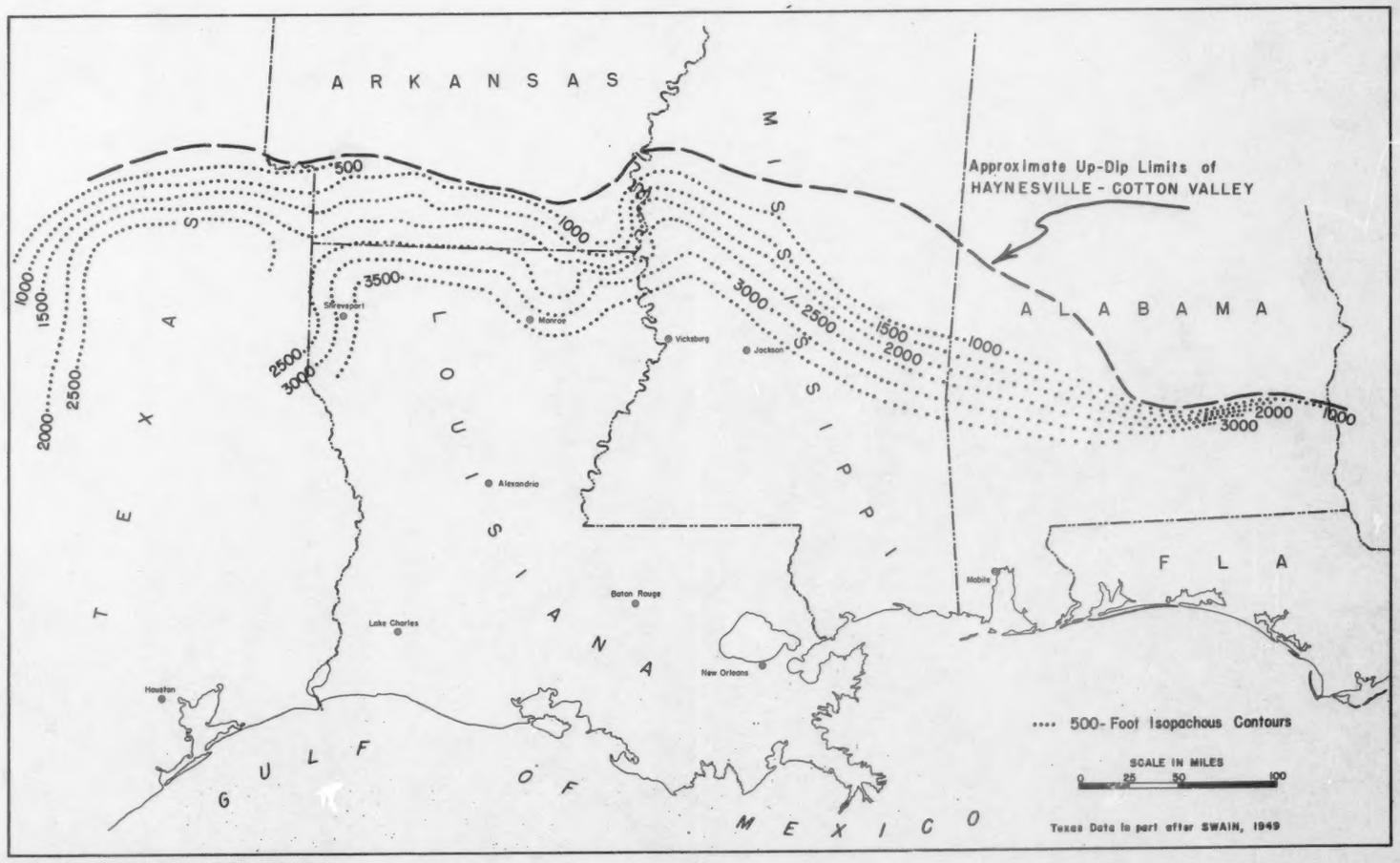

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STRUCTURAL FEATURES AND ISOPACHOUS CONTOURS

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SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF THE UNITED STATES AND MEXICO

PART III: VOLUME OF MESOZOIC AND CENOZOIC SEDIMENTS IN CENTRAL GULF COASTAL PLAIN OF UNITED STATES

BY GROVER E. MURRAY

ABSTRACT

Gulfward-dipping Mesozoic and Cenozoic sediments underlie approximately 145,000 square miles in the Central Gulf Coast between Texas on the west and Georgia on the east. Pre-Cretaceous, Coahuilan, Comanchean, and early Gulfian rocks are predominantly red-bed clastics in the eastern portion of this area; westward and downdip marine facies predominate. Extensive marine deposits comprise the middle and late Gulfian; arenaceous facies predominate in the east; argillaceous and calcareous facies are prevalent westward and downdip. Tertiary deltaic sediments center in Louisiana and Mississippi; eastward and down-dip marine deposits prevail. Fluviatile and deltaic Quaternary deposits occur as a surficial mantle over much of the Central Gulf Coast; offshore these deposits are replaced by marine facies.

Stratigraphic studies indicate that major Jurassic and Lower Cretaceous sedimentary units are typically elongate-lenticular while those of the Upper Cretaceous and Cenozoic are ladle-shaped. During Jurassic and Cretaceous times the major source of sediments was apparently eastern United States. In the Cenozoic, appreciable quantities of material appear to have come from western United States.

Regional isopachous maps illustrate variations in thickness of Mesozoic and Cenozoic stratigraphic units. In the emerged (onshore) portion of the plain, deep wells prove the presence of at least 265,000 cubic miles of sediments. Interpolations based on regional studies indicate that the total volume of Mesozoic and Cenozoic deposits in this area will exceed 300,000 cubic miles.

The known volumes of sediments that accumulated in the emerged (onshore) portion of the Central Gulf Coast during these times are:

	Cubic miles*
Cenozoic	105,400
Quaternary	4,000
Tertiary	101,400
Mio-Pliocene (?)	4,700
Miocene	21,875
Upper Eocene-Oligocene	10,025
Middle Eocene	16,925
Paleocene-Lower Eocene	47,875
Mesozoic	133,375–159,875
Cretaceous	99,350
Gulfian	40,175
Coahuilan-Comanchean	59,175
Upper Jurassic	34,025–60,525
Pre-Upper Jurassic (?)	26,500

*Minimum figures are given.

Few data are available on volumes of sediments in the submerged (off-shore) portion of the plain, which has an area of approximately 140,000 square miles. Conservatively, it is estimated that at least 200,000 cubic miles of Mesozoic and Cenozoic deposits is present. On the other hand, some evidence indicates the total may exceed 500,000 cubic miles.

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Introduction

The Central Gulf Coastal Plain (Pl. 1, A) is here considered as that area between the Texas-Louisiana and Alabama-Georgia State lines south of the approximate latitude of Memphis, Tennessee. So defined, it includes all or parts of Louisiana, Mississippi, Arkansas, Tennessee, and Alabama between 85° and 94° West Longitude and 29° and 35° North Latitude. The Sabine River on the west and the Chattahootchee-Apalachicola River system on the east form convenient, natural boundaries. The emerged portion (that part above the sea) of the Central Gulf Coastal Plain approximates 145,000 square miles; the submerged portion to a depth of 10,000 feet includes about 140,000 square miles. Gulfward-dipping post-Paleozoic sedimentary rocks (Fig. 1) underlie the entire area in an average thickness of almost 2 miles. In areas of greatest sedimentary accumulation, Mesozoic and Cenozoic deposits approach 7–8 miles in thickness.

The general Gulfward homoclinal dip is influenced by two major negative structural anomalies: the Gulf Coast Geosynclinal Trough and the Mississippi Structural Trough; and by four major positive structural features: the Sabine Uplift, the Monroe-Sharkey Uplift, the Jackson Uplift, and the Wiggins Anticline. Numerous smaller positive and negative structural features combine to form a structural pattern far more complex than imagined by those unfamiliar with the region (Pl. 1, A, B).

Jurassic and questionably pre-Jurassic deposits are entirely subsurface in their occurrence in the Central Gulf Coastal Plain. Comanchean sediments are restricted to the subsurface except for a small outcrop area in southwestern Arkansas. Gulfian and Cenozoic strata crop out over all the remainder of the Central Gulf Plain.

Stratigraphic studies indicate that major Jurassic and Lower Cretaceous (Coahuilan and Comanchean) deltaic masses tend to be elongate-lenticular, while those of the Upper Cretaceous (Gulfian) and Cenozoic are ladle shaped. Deposits accumulated during the various major sedimentary epochs to maximum thicknesses approximating 3000 feet. The rate of sedimentation and the rate of subsidence maintained approximate equality for extended periods of time as evidenced by the shallow depositional environment of the sediments.

Source of Data and Acknowledgments

The density of deep wells in the Central Gulf Plain affords a wealth of three-dimensional Mesozoic and Cenozoic geologic information

virtually unexcelled elsewhere in the world. The isopachous maps from which the sedimentary volumes for this area have been computed are based on all pertinent wildcat and field-well data available to January 1, 1950. Basically, they follow the pattern of illustration utilized by Ver Wiebe (1932) in his studies of the distribution and thickness of the Paleozoic system of the United States and by Fisk (1944) in his report on the Mississippi River. They represent, by the writer's rejection, acceptance, and interpretation, a distinct and separate analysis of the data.

Many individuals and organizations have contributed information and suggestions to the study. To all these, sincere thanks and appreciation are extended. Special acknowledgment is due H. N. Fisk, who originally conceived certain of the ideas expressed here and whose earlier works (1943; 1944) guided these efforts. However, all interpretations herein are those of the writer, and full responsibility for errors is his.

Terminology

The stratigraphic terminology employed is largely that of current vogue (Fig. 1). The writer neither advocates nor condones its usage. It is basically a lithologic terminology which by default has been applied dually to both rock and time-stratigraphic units. Large-scale time and time-rock subdivisions are recognized and utilized rather universally in coastal plain terminology. However, no time and time-rock units below epoch and series rank are accepted yet in Mesozoic and Cenozoic nomenclature of the Gulf and Atlantic Coastal Plain.[1] Instead,

SYSTEM	SERIES	GROUP OR STAGE
QUATERNARY	RECENT	
	PLEISTOCENE	
TERTIARY	PLIOCENE	
	MIOCENE	GRAND GULF
	OLIGOCENE	VICKSBURG
	EOCENE	JACKSONIAN
		CLAIBORNE
		WILCOX
	PALEOCENE	MIDWAY
CRETACEOUS	GULFIAN	NAVARRO
		TAYLOR
		AUSTIN
		EAGLEFORD
		WOODBINE (TUSCALOOSA)
	COMANCHEAN	WASHITA
		FREDERICKSBURG
		TRINITY (INCLUDING TRAVIS PEAK OF TEXAS)
	COAHUILAN	NUEVO LEON & DURANGO GROUPS OF MEXICO (HOSSTON–SLIGO)
JURASSIC		COTTON VALLEY
		HAYNESVILLE
		SMACKOVER — LOUARK GROUP
		NORPHLET
PRE-JURASSIC (?)		PRE-NORPHLET

Figure 1.—Generalized Geologic Column, Central Gulf Coastal Plain

[1] Murray and Wilbert (1950) have recently redefined Jacksonian Stage and Age. Murray (1952) has defined Vicksburg Stage and Midway Stage (Holland, Hough, and Murray, 1952). Acceptance of this terminology and other to-be-defined stages and ages will, of course, depend upon general usage.

lithologic names long applied to distinct rock groups have been expanded to include diverse lithologic types and thereby have been utilized in a time-rock sense. No quarrel is raised with the designated equivalency of most of these units. Stratigraphic impropriety is evident, however, in the usage, without designation or definition, of good, valid, long-recognized rock names for indicating time equivalency.

Mesozoic Stratigraphy and Sedimentary Volumes

Pre-Upper Jurassic (?)

Sediments underlying the definitely Upper Jurassic Smackover limestone and equivalent sediments are the least well known of any deposits discussed here. Based on drilling during the last 20 years, the sequence is divisible into:

Smackover limestone and equivalent deposits
Norphlet formation
Louann salt
Werner anhydrite and red clastics
Morehouse-Eagle Mills clastics

The stratigraphic relations of the Smackover and Norphlet are such that the Norphlet also is considered definitely Upper Jurassic. Diversity of opinion exists as to the exact age of the pre-Norphlet deposits. Some geologists consider them Upper Jurassic; others questionably assign them to the Permian; it is conceivable that they are Middle or Lower Jurassic or even Triassic. Past and present members of the Shreveport Geological Society, in particular W. G. Weeks, R. T. Hazzard, W. C. Spooner, B. W. Blanpied, and T. H. Philpott, have pioneered in the study of these deposits. The sequence presented here is largely their efforts. Their latest publication (Philpott and Hazzard, 1949) considers the pre-Norphlet beds questionably Permian.

These deposits are entirely subsurface (Pl. 1, B), and data concerning them are limited accordingly by the number of wells which penetrate them. Basically they consist of shoreward (updip) facies that grade rapidly into offshore (downdip) or basin facies. The shoreward facies are composed of prominently red and coarse-grained clastics, while the offshore facies are darker and finer clastics, carbonates, and evaporites. A thick bed of salt is present in the middle of the sequence. These major lithologic facies are known definitely from well data in northeast Texas, southern Arkansas, and northern Louisiana. Very little positive information is available concerning them in Alabama and Mississippi.

Volumetrically, knowledge concerning these deposits is scarce. By appraisal and interpolation they are judged to approximate 31,500 cubic miles in the emerged portion of the plain (Fig. 4; Table 1). In the final analysis, this figure may well double or treble. In the area of the submerged plain, no information is available on volumes. If the mother bed of salt supplying the domes of the near-shore and submerged portions of the plain is continuous with that supplying the more interior domes, the total volume of salt may well be measured in tens of thousands of cubic miles. On the contrary, if these mother salt beds are of different ages, there might be no pre-Norphlet sediments beneath the modern strand and the submerged portion of the plain. Present information suggests that these deposits are thickest in north Louisiana and south Arkansas.

Upper Jurassic

Definite Upper Jurassic deposits overlie the Louann salt in the interior portions of the Central Gulf Coast. The Jurassic age is based on fairly abundant fossils recovered from cores and cuttings of wells. These same wells provide data for division of these sediments into:

Cotton Valley group
Louark group[2]
Haynesville (including Buckner anhydrite) (Philpott and Hazzard, 1949)
Smackover
Norphlet

Updip and in the eastern portion of the area these strata are red, generally coarse clastics. Downdip and in the west, they are dark, generally fine clastics with appreciable quantities of carbonates and evaporites (salt and anhydrite). Reef limestone facies are known in north Louisiana and south Arkansas. Depo-

[2] Name adopted by Shreveport Geological Society, May 1951.

centers of the Norphlet-Smackover appear to have been in the north Louisiana-south Arkansas area and in Mississippi (Pl. 1, C; 4, D).

TABLE 1.—VOLUMETRIC SUMMARY OF MESOZOIC AND CENOZOIC SEDIMENTS IN EMERGED PORTION OF CENTRAL GULF COASTAL PLAIN

	Cubic miles		
	Known	Estimated	Total
Cenozoic	105,400+	17,200+	122,600+
Quaternary	4,000+	500+	4,500+
Recent	1,000+	500+	1,500+
Pleistocene	3,000+		3,000+
Tertiary	101,400+	16,700+	118,100+
Neogene			
Mio-Pliocene (?)	4,700+	—	4,700+
Miocene	21,875+	11,800+	33,675+
Upper Fleming	3,300+	1,000+	4,300+
Lower Fleming	4,850+	4,000+	8,850+
Upper Catahoula	8,075+	4,600+	12,675+
Lower Catahoula	5,650+	2,200+	7,850+
Paleogene			
Chickasawhay	4,425+	500+	4,925+
Oligocene (Vicksburg)-Upper Eocene	5,600+	500+	6,100+
Middle Eocene	16,925+	700+	17,625+
Lower Eocene-Paleocene	47,875+	3,200+	51,075+
Mesozoic	133,375–159,875+	26,000+	159,375–185,875+
Cretaceous	99,350+	15,000+	114,350+
Gulf Series	40,175+	4,500+	44,675+
Comanche Series	33,275+	7,500+	40,775+
Fredericksburg-Washita-post-Washita	14,475+	2,500+	16,975+
Trinity	18,800+	5,000+	23,800+
Coahuila Series (Hosston-Sligo)	25,900+	3,000+	28,900+
Upper Jurassic	34,025–60,525+	6,000+	40,025–66,525+
Cotton Valley-Haynesville	23,150+	5,000+	28,150+
Smackover-Norphlet	10,875+	1,000+	11,875+
Pre-Upper Jurassic (?)	26,500+	5,000+	31,500+

Depocenters of the Haynesville-Cotton Valley were in north Louisiana and in southwestern Alabama where about 4000 feet of strata accumulated (Pls. 1, D; 4, D).

Information concerning the volume of Norphlet deposits is scarce. On the basis of available data, they are estimated to exceed 5000 cubic miles. Somewhat better data are accessible for the Smackover limestone, but even this information is quite limited. The known Smackover volume in the Central Gulf is 5875 cubic miles.

Haynesville-Cotton Valley deposits are treated as a unit for ease of handling and correlation over the entire area. Isopachous maps based on currently available data evidence the presence of at least 23,150 cubic miles of sediment (Fig. 4; Pl. 1, D; Table 1). Recent wells suggest that the figure may exceed 30,000 cubic miles.

No data are available concerning thicknesses or volumes of Upper Jurassic deposits in the submerged portion of the province.

Cretaceous System

Coahuila Series.—In the Central Gulf Coastal Plain, the oldest Cretaceous sediments consist of a lower clastic facies termed Hosston and an

upper clastic and carbonate facies termed Sligo. So far as known, they are entirely subsurface in their occurrence in this area (Pl. 1, B). The Hosston facies is generally red and varies from fine- to coarse-grained clastics; it prevails updip and in the eastern portion of the area. The Sligo facies is predominantly some shade of gray carbonate or fine-grained clastic; it predominates westward and downdip. The two facies mutually replace each other from area to area. Sedimentation in this period was concentrated in north-central Louisiana.

Terminology proposed by the Shreveport Geological Society is employed here. Inclusion of the Hosston-Sligo sequence in the Coahuila Series follows Imlay (1945) who also assigned these strata to the Nuevo Leon and Durango groups of Mexico.

In the emerged portion of the Gulf Plain, 25,900 cubic miles of Coahuilan sediments are known in the subsurface. Another 3000 cubic miles can be estimated reasonably to exist in the same area. No data are available concerning their existence or their volume beneath the Gulf of Mexico (Fig. 4; Pl. 2, A; Table 1).

Comanche Series.—All deposits younger than the Coahuilan (Hosston-Sligo) and older than the Gulfian (Woodbine-Tuscaloosa) are included in the Comanche Series. The series includes strata normally assigned to:

Washita group
Fredericksburg group
Trinity group

Certain subsurface sediments (Dantzler and South Tyler formations of literature), believed to be Comanchean younger than the Washita group, are also included.

Facies of the Comanchean are similar to previously described facies of the Upper Jurassic and Coahuilan sediments. Red, fine- to coarse-grained clastics predominate in the updip areas and in the eastern portion of the Central Gulf Plain. Gray to black carbonates and fine-grained clastics predominate to the west and downdip. A prominent bed of anhydrite is present throughout most of the area penetrated by the drill. Small reef limestones, generally biostromal, are fairly common in the Trinity of northwestern Louisiana and northeastern Texas. Relatively recent drilling in northeast Texas and west-central Louisiana has revealed the presence of large, thick, extremely porous, probably reef limestones in downdip Trinity, Fredericksburg, and Washita sediments.

Trinity deposition was concentrated in north Louisiana and south-central Mississippi where approximately 4000 feet of sediments accumulated (Pl. 4, D). The depocenter of Fredericksburg-Washita-post-Washita sedimentation appears to have been in south-central Mississippi (Pl. 4, D).

In the emerged portion of the plain, Trinity deposits accumulated in the known amount of 18,800 cubic miles. An additional 5000 cubic miles can reasonably be inferred in this area. No data are available concerning the occurrence or amount of Trinity sediments beneath the submerged portion of the plain (Fig. 4; Pl. 2, B; Table 1).

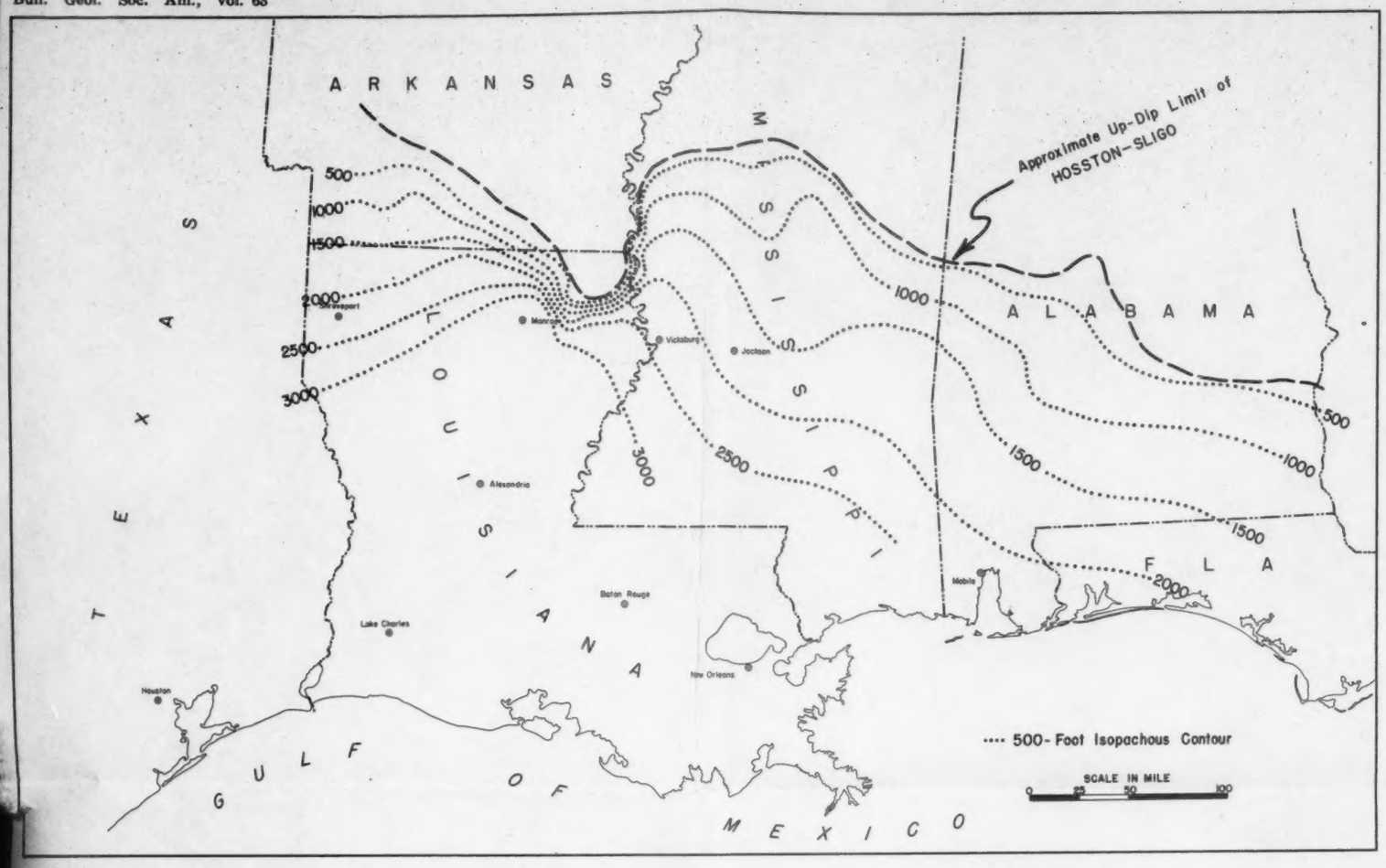
Fredericksburg-Washita-post-Washita sediments accumulated in the area of the submerged plain in the known amount of 14,475 cubic miles; 2500 additional cubic miles can be extrapolated with a fair degree of certainty in this area (Fig. 4; Pl. 2, C; Table 1).

Known Comanchean deposits total 33,275 cubic miles; 7500 additional cubic miles are rather definitely present, giving an estimated total of 40,750 cubic miles for the Comanchean beneath the emerged plain (Fig. 4; Table 1).

Available data do not reveal definitely the presence of equivalent strata beneath the Gulf of Mexico, but they certainly evidence strongly their probable occurrence in this area (Fig. 4; Pls. 2, B; 2, C).

Gulf Series.—The Gulf Series includes those deposits younger than post-Washita (Dantzler and South Tyler formations of published literature) and older than the basal Paleocene marls and sands (Kincaid and Clayton).

Basal Gulfian sediments (Woodbine-Tuscaloosa) are prevailingly coarse to fine clastics. They are generally red at the outcrop, but change to gray or black downdip where marine facies are well developed. Younger Gulfian deposits (Eagleford-Austin-Taylor-Navarro) vary from chalks and limestones to coarse-grained clastics. In central and eastern Alabama, virtually this entire sequence is clastic. Westward and downdip, marls, chalks, and limestones constitute the bulk of the sequence. The well-known Selma chalk includes chalky equiva-



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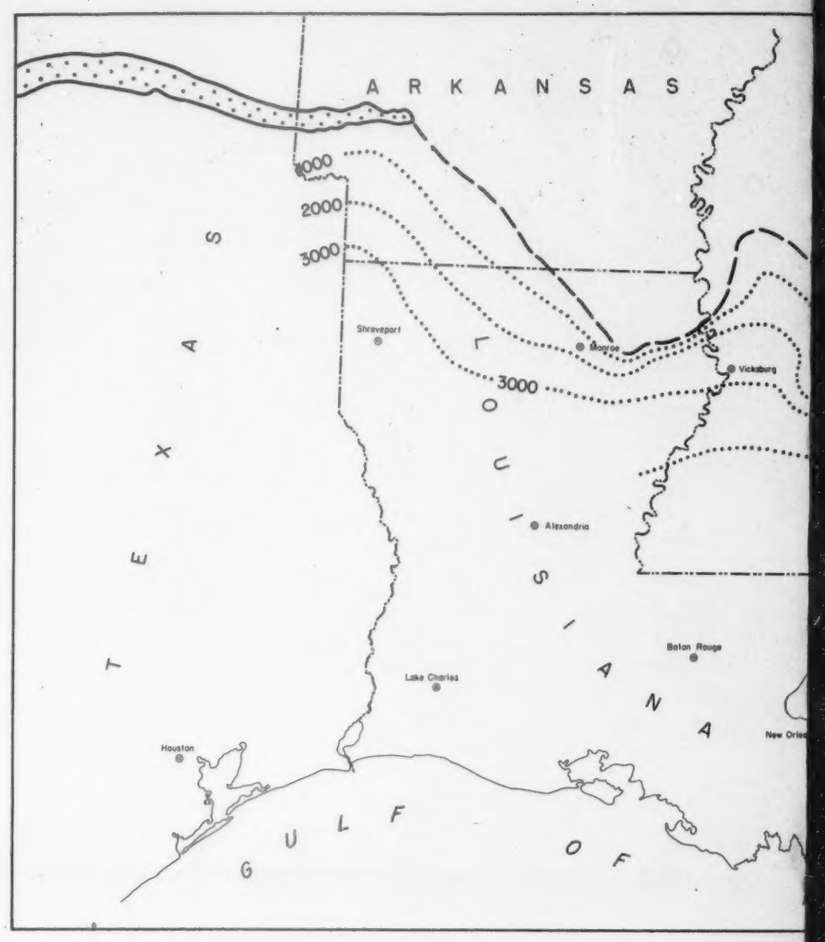

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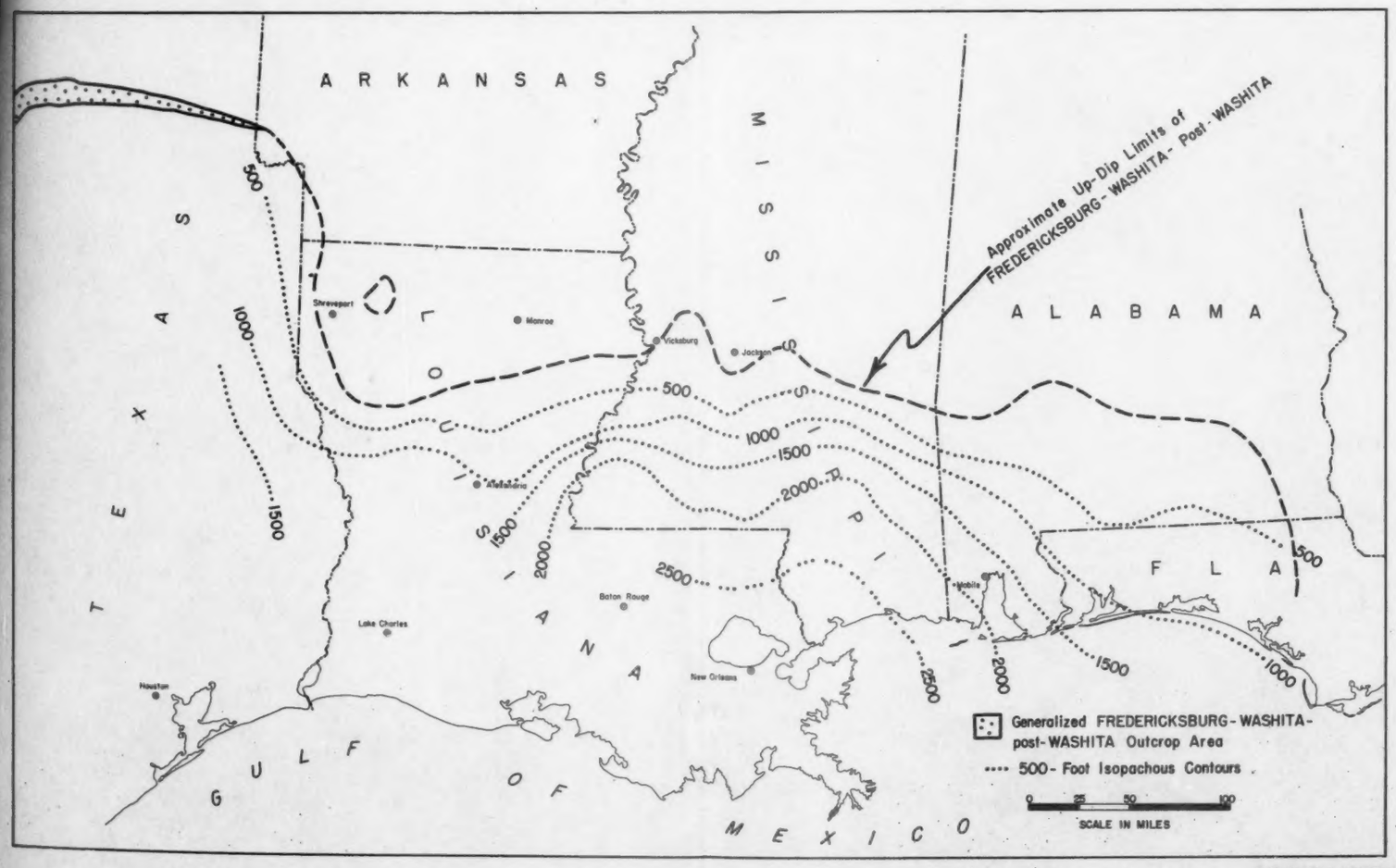

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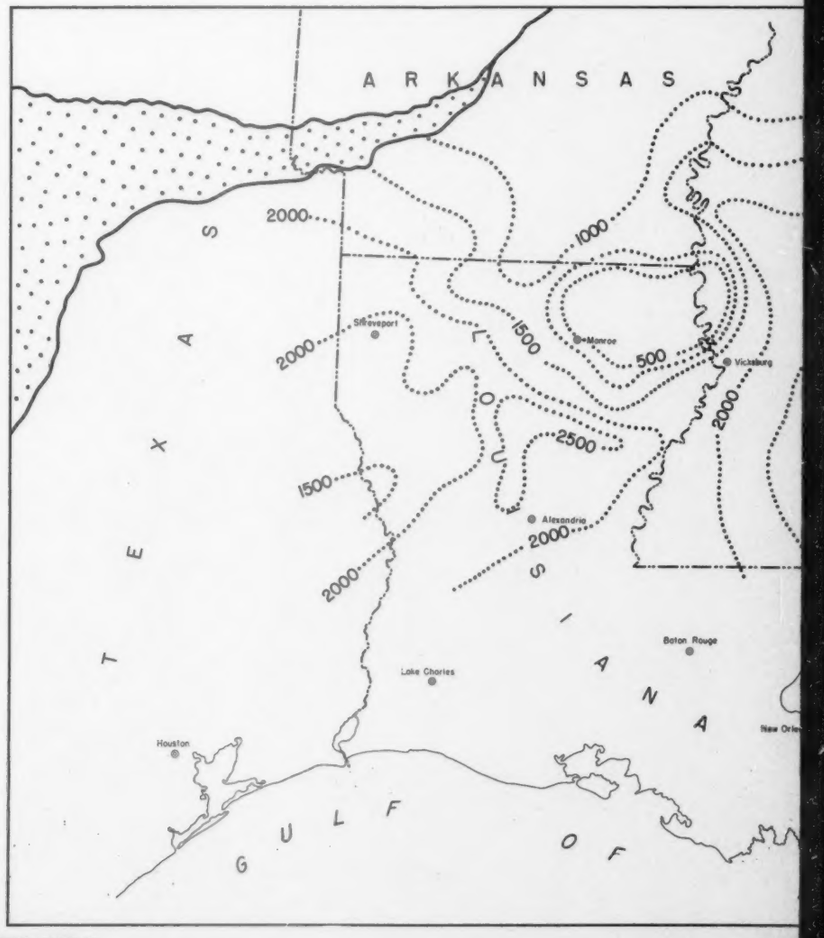


D

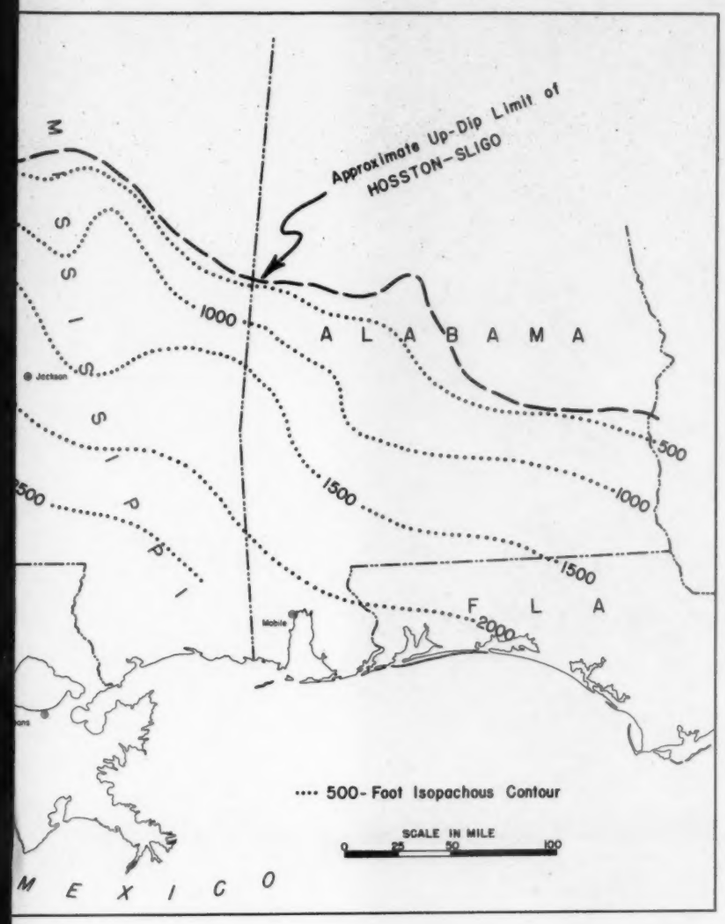
ISOPACHOUS CONTOURS

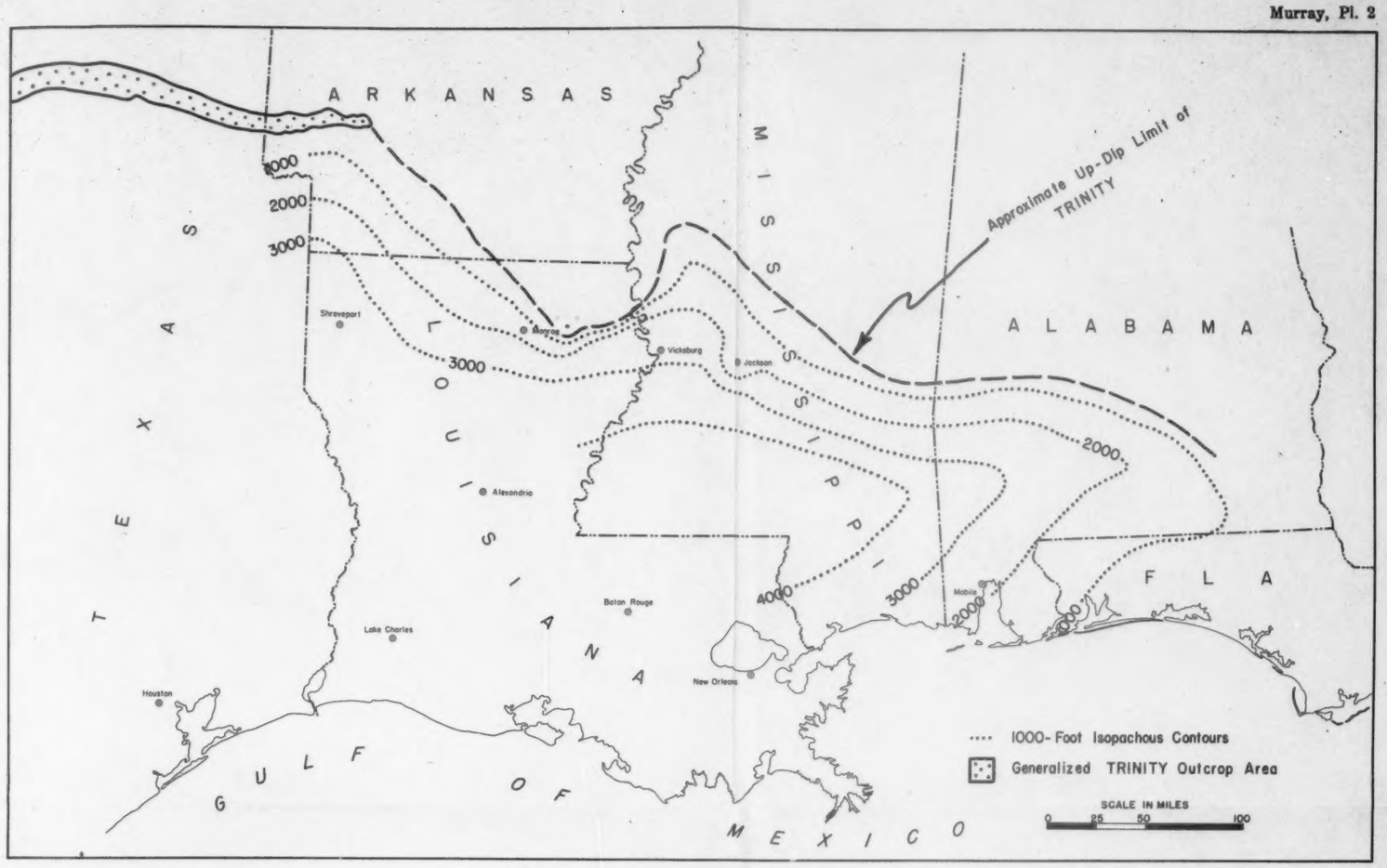
A. ISOPACHOUS CONTOURS OF COAHUILA SERIES (HOSSTON-SLIGO)

B. ISOPACHOUS CONTOURS OF COMANCHE SERIES (TRINITY GROUP)

C. ISOPACHOUS CONTOURS OF COMANCHE SERIES (FREDERICKSBURG-WASHITA-POST-WASHITA)

D. ISOPACHOUS CONTOURS OF UPPER CRETACEOUS (GULF SERIES)





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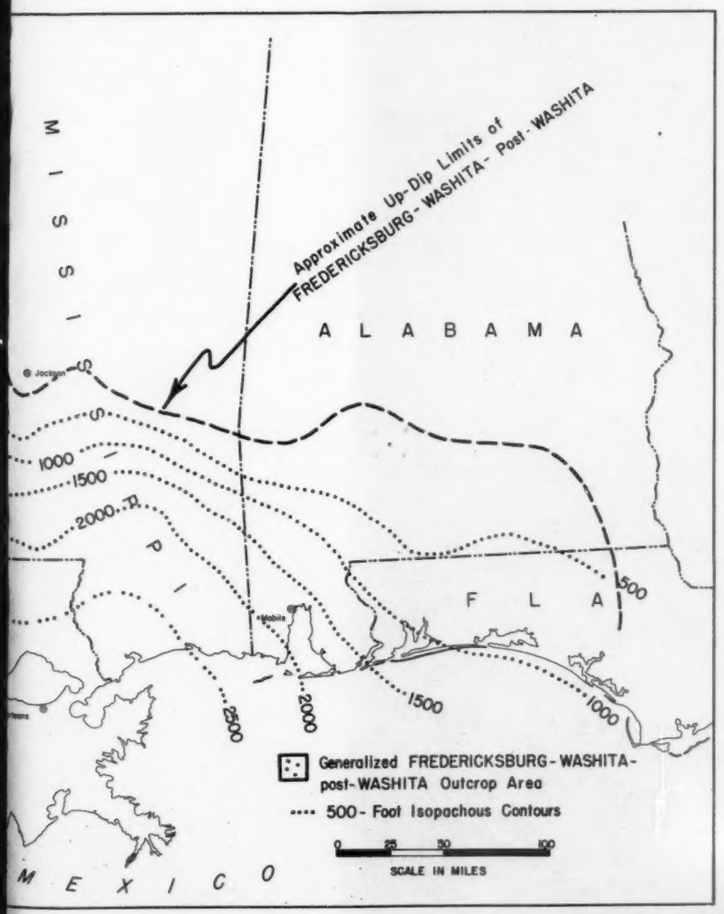
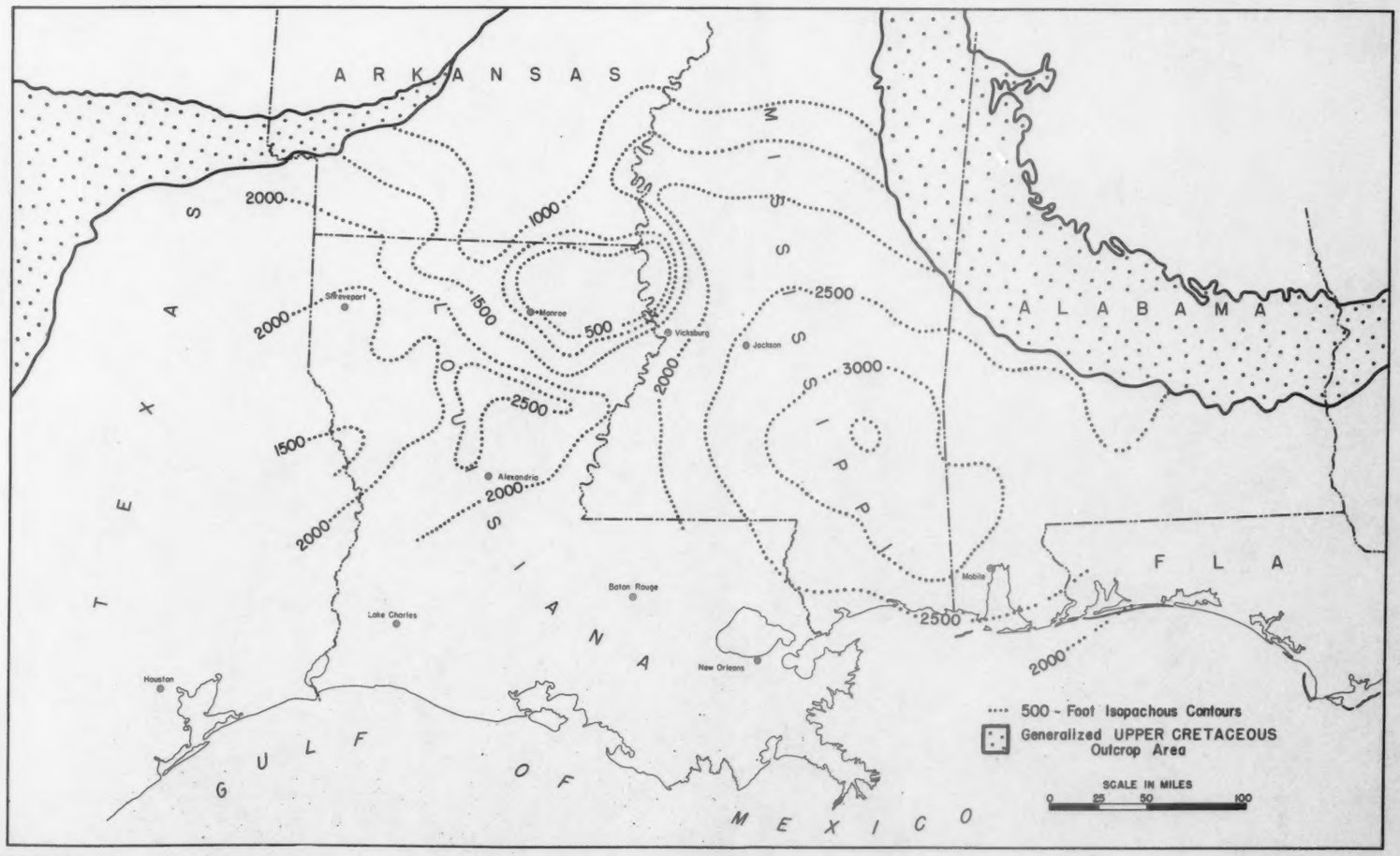




D

ISOPACHOUS CONTOURS

SOPACHOUS CONTOURS OF COAHUILA SERIES (HOSSTON-SLIGO)

SOPACHOUS CONTOURS OF COMANCHE SERIES (TRINITY GROUP)

C. ISOPACHOUS CONTOURS OF COMANCHE SERIES (FREDERICKSBURG-WASHITA-POST-WASHITA)

D. ISOPACHOUS CONTOURS OF UPPER CRETACEOUS (GULF SERIES)

lents of the Eagleford, Austin, Taylor, and Navarro. Each sedimentary sequence exhibits an almost uniform change from appreciably coarse-grained clastics in the updip facies through finer-grained clastics to calcareous or carbonate rocks in downdip areas. Late Taylor (?) and Navarro reef limestones occur atop the Jackson Uplift of Mississippi and the Monroe-Sharkey Uplift of Louisiana, Arkansas, and Mississippi. Volcanic facies are also prominent in the Monroe-Sharkey Uplift area.

Lower Gulfian (Woodbine-Tuscaloosa-Eagleford-Austin) deposition was concentrated in eastern Mississippi (Pl. 4, D). Later deposition (Taylor-Navarro) was more uniformly distributed although some concentration of sediments appears to have occurred in northwestern Louisiana and in eastern Mississippi and western Alabama. The depocenter in eastern Mississippi witnessed the accumulation of slightly more than 3500 feet of Gulfian deposits (Pls. 2, D; 4, D).

In the emerged portion of the Central Gulf, 40,175 cubic miles of Gulfian sediments is known. Another 4500 cubic miles can reasonably be demonstrated to be present, making an estimated total beneath the emerged area of 44,675 cubic miles (Fig. 4; Table 1). No data are available concerning the extent or volume of Gulfian deposits beneath the Gulf although it can be demonstrated that they exist (Pl. 2, D).

Cenozoic Stratigraphy and Sedimentary Volumes

Tertiary

Paleogene.—Tertiary sediments are here grouped into older Tertiary (Paleogene) and younger Tertiary (Neogene) (Figs. 1, 4). This general division is followed in order to emphasize the concentration of deltaic sedimentation in the Central Gulf Plain in both the early and late Tertiary. The extensive deltaic accumulation of the Miocene and Pliocene in this region still continues, and the writer favors inclusion of all post-Oligocene deposits and time in the Neogene. Structural and stratigraphic evidence in the Central and Eastern Gulf areas indicates that the major break in the Tertiary sequence occurred at the close of the Oligocene. Miocene sediments overlap the Oligocene and upper Eocene (?) strata from east to west. Also, distinct structural deformation of the Oligocene sediments in this area in many places does not involve Miocene strata. The withdrawal of marine waters from the Embayment portion of the Mississippi Structural Trough during and after Jacksonian time, the absence of known Oligocene strata on the Atlantic Coastal Plain north of Georgia, and the extensive overlap of Tertiary and Cretaceous deposits by the Miocene on the Atlantic Plain further evidence the magnitude of this break. Evidence for such a break is most prominent (1) in updip (nearshore) areas in the Central and Eastern Gulf Coastal Plain and (2) in such areas as the Atlantic Coastal Plain which were not associated with thick deltaic accumulation. Little evidence of such a break is known in the subsurface of the Central and Western Gulf region where thick deltaic and marine deposits accumulated.

Paleocene-Lower Eocene deposits consist of an extensive, sandy to argillaceous, basal chalk or marl; a thick, widespread, dark marine prodeltaic shale; and thick, variable deltaic sands and shales with interbedded marine and brackish-water sediments. The lower marls and dark shales commonly have been termed Midway; the sandy facies have been referred to as Wilcox. Local reef facies are developed in the Wilcox sediments in southern Mississippi and western Alabama. Calcareous, marine sand facies are present in the Midway shales in southern Mississippi and Alabama and in southeastern Louisiana.

Deposition was concentrated in south-central Mississippi and in southwestern Louisiana during this time (Pl. 4, D). Approximately 4500 feet of these strata accumulated in southwestern Mississippi; slightly more than 5200 feet of deposits formed in southwestern Louisiana and in southeastern Texas (Pl. 3, A).

Middle Eocene strata include two depositional units consisting of extensive glauconitic, fossiliferous sands at the base; above these are fossiliferous to carbonaceous shales; and then lignitic, fluviatile to deltaic sands and shales. Updip facies consist of complex, near-shore deltaic, marginal marine, and fluviatile sands, silts, and clays. Occasional thin, generally

local, fossiliferous lenses evidence the proximity of the sea and attest to the shallow environment of deposition in this area. Downdip, the sediments are replaced by thick, marine shales and calcareous deposits. Biostromal reef facies developed in the middle of this sequence in southeastern Mississippi and southwestern Alabama. Bentonitic beds are present in northern Louisiana.

Deposition during the Middle Eocene was concentrated in western Mississippi and eastern Louisiana, where about 2600 feet of strata accumulated; and in southwestern Louisiana and southeastern Texas where approximately 3500 feet of sediments accumulated (Pls. 3, B; 4, D).

In the Upper Eocene (Jacksonian) and Oligocene, marine sedimentation prevailed in most of the Central Gulf. Marginal and deltaic deposition was prominent in the late Jacksonian and Oligocene in the western portion of this area. The Jacksonian strata consist of a basal, fossiliferous, glauconitic sand overlain by fossiliferous, partially glauconitic sands, clays, marls, and soft, chalky limestones. Fine- to medium-grained clastic, often carbonaceous strata occur in the upper Jacksonian of western Mississippi and Louisiana. Tuffaceous and bentonitic sediments are present from place to place and, in general, increase in amounts westward. Biostromal reef facies formed atop the Wiggins anticline and southeast Mississippi Platform in southeast Mississippi and southwest Alabama. Oligocene sediments consist of carbonaceous to lignitic sands, silts, and clays in most of Louisiana; eastward they are replaced by fossiliferous, glauconitic sands, marls, and limestones.

Sedimentation was concentrated during the Jacksonian and Oligocene in southwestern Louisiana and coastal Texas (Pls. 3, C; 4, D). In the Central Gulf region, these deposits attained a maximum thickness of slightly more than 2000 feet.

In the emerged portion of the plain, known Paleogene deposits total 74,825 cubic miles. Presence of an additional 4900 cubic miles can be estimated with fair assurance. The known Paleocene-Lower Eocene deposits constitute 47,875 cubic miles, the Middle Eocene 16,925 cubic miles, and the Jacksonian-Oligocene 10,025 cubic miles. No definite data are available to prove the existence of these strata beneath the submerged portion of the plain, but isopachous and stratigraphic studies based on deep-well information suggest their almost certain presence (Fig. 4; Pls. 3, C; 3, D; Table 1).

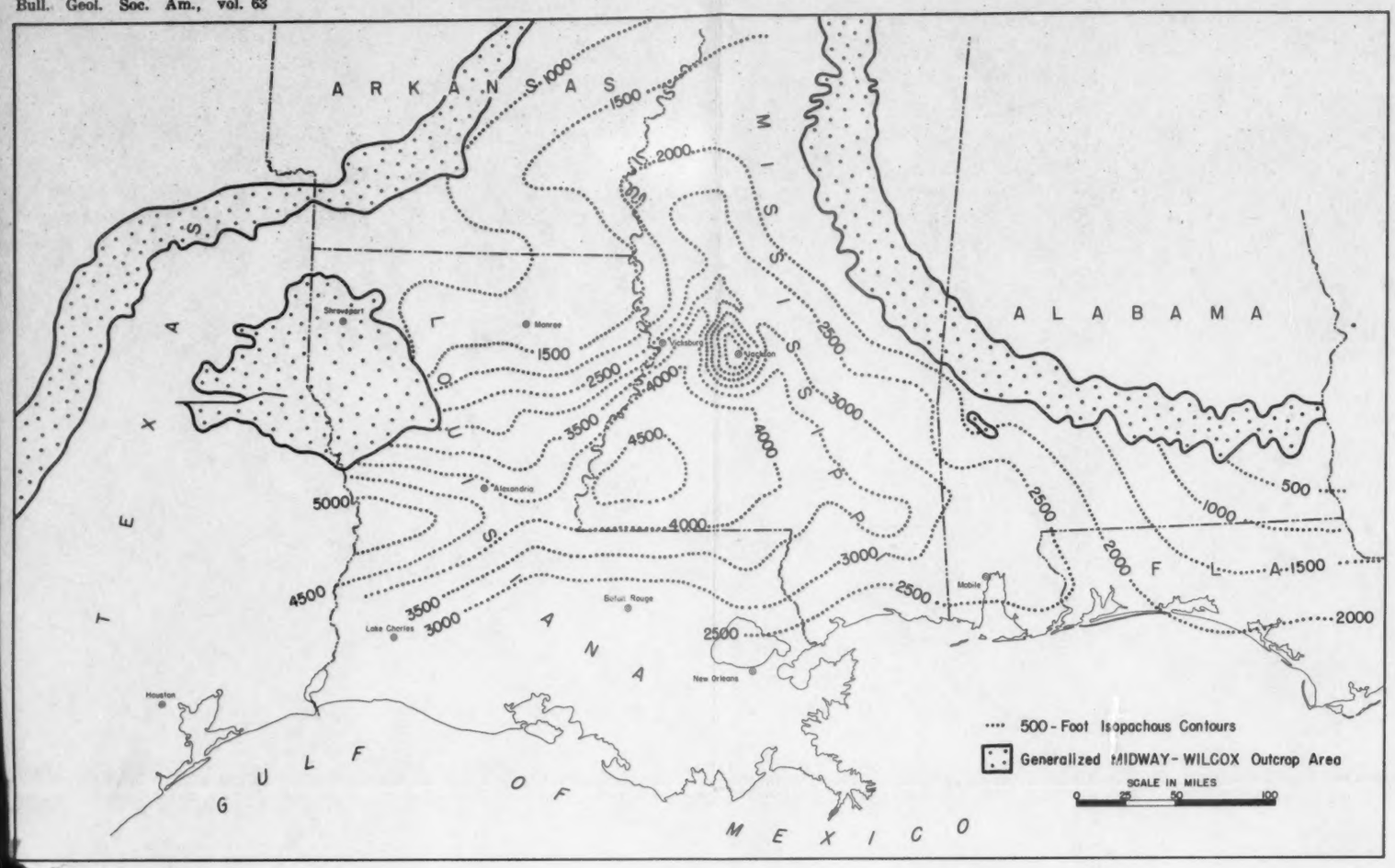
Neogene.—During the late Tertiary, concentrated deltaic deposition occurred in the Central Gulf Coastal Plain to an extent almost unparalleled. With some modification in the Quaternary, this condition has continued to modern times. These late Tertiary deposits, grouped for convenience as Neogene, include all deposits younger than the accepted Oligocene of the Mississippi-Alabama area and older than the Pleistocene. They are commonly referred to the Miocene and Pliocene (?). Updip facies consist of complexly interbedded, fluviatile, marginal, and deltaic sediments which grade downdip into finer-grained and more calcareous marine clastics. The entire sequence is characterized by great thickening of individual units and by rapid facies changes to thick, marine shales downdip. The total thickness of these deposits has not been penetrated by 15,000-foot wells near the modern Louisiana shore.

Depositional sites shifted from place to place in south Louisiana during the Neogene. During at least four periods of deposition, approximately 3000 feet of deposits accumulated in separate depocenters (Figs. 2, 3; Pls. 3, D; 4, A–D). In the emerged portion of the plain, total known deposits amount to 26,575 cubic miles. An additional 11,800 cubic miles can be estimated with considerable certainty (Fig. 4; Table 1).

In the submerged portion of the plain, deep wells indicate more than 13,000 feet of Neogene sediments. No evidence of Gulfward thinning of these strata has been found. The volume of deposits beneath the submerged portion of the plain will certainly equal and probably exceed the 38,375 cubic miles known to be beneath the emerged plain.

Quaternary

Pleistocene and Recent sediments in the Central Gulf region consist of widespread fluviatile, marginal, deltaic, and marine facies



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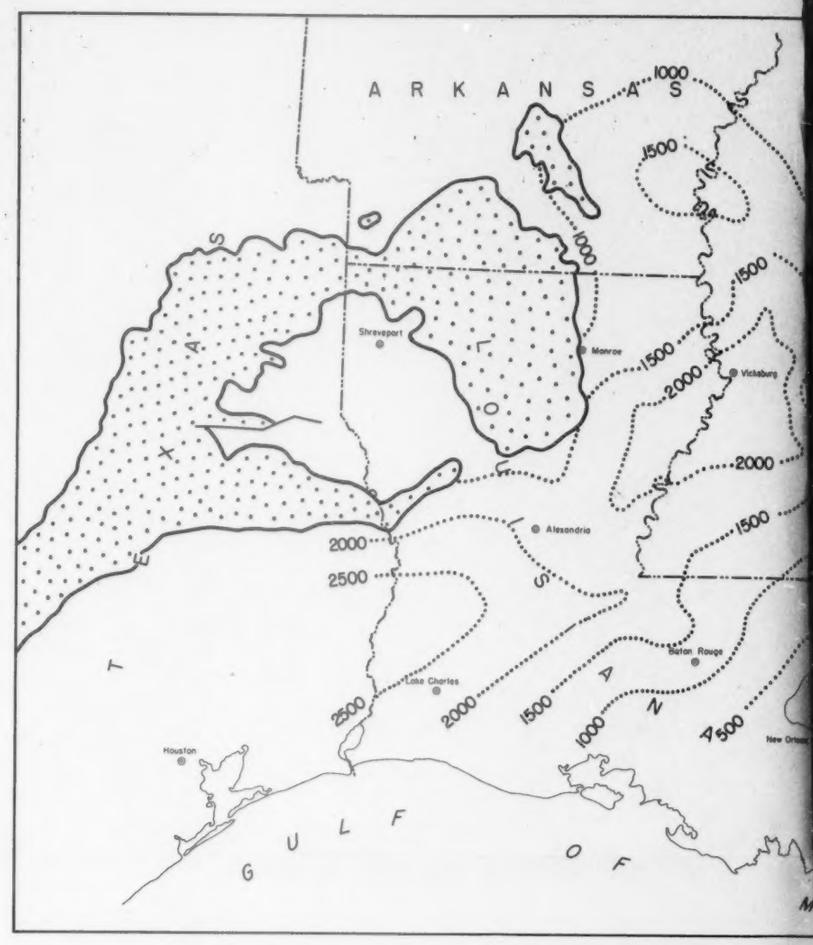

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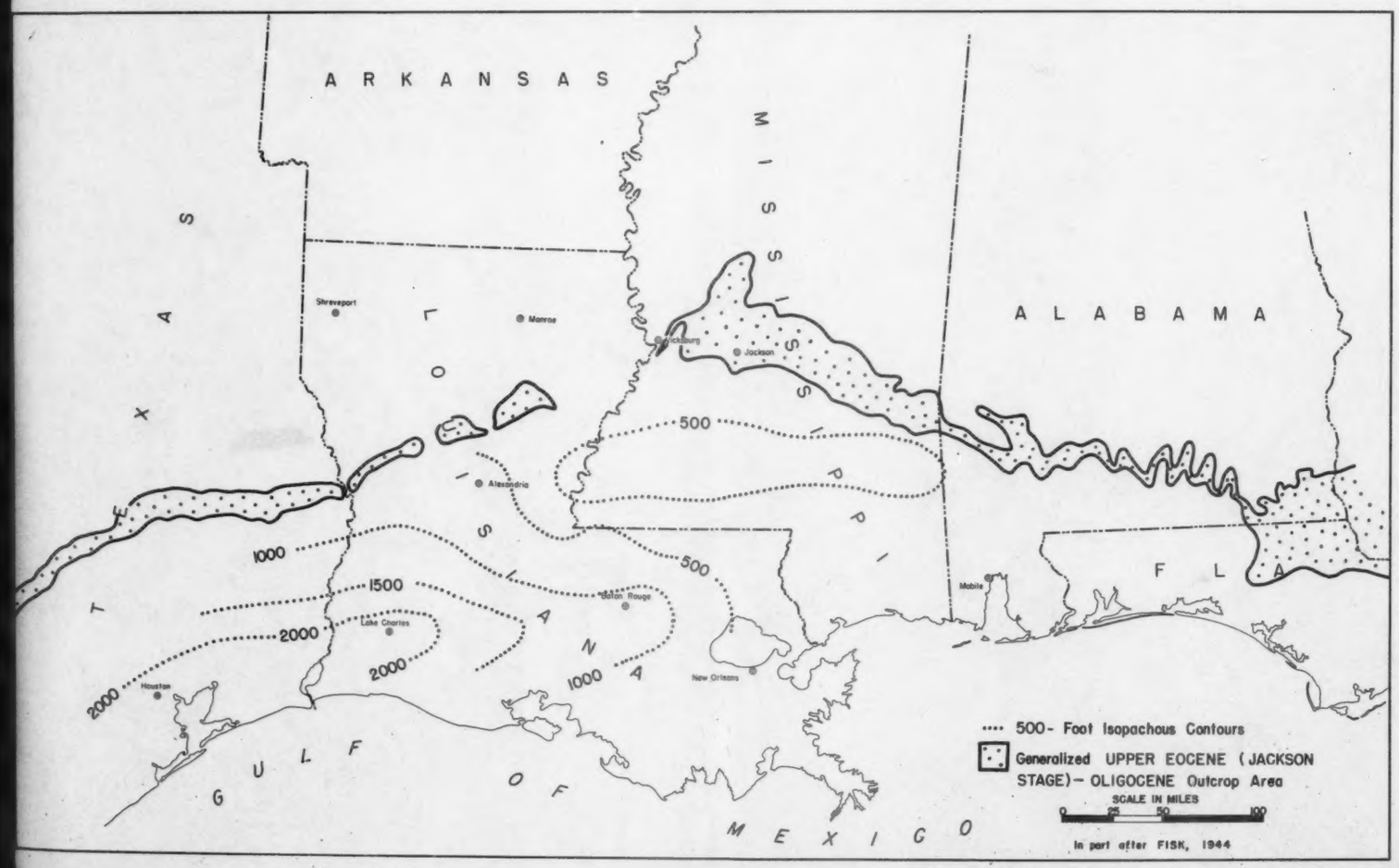

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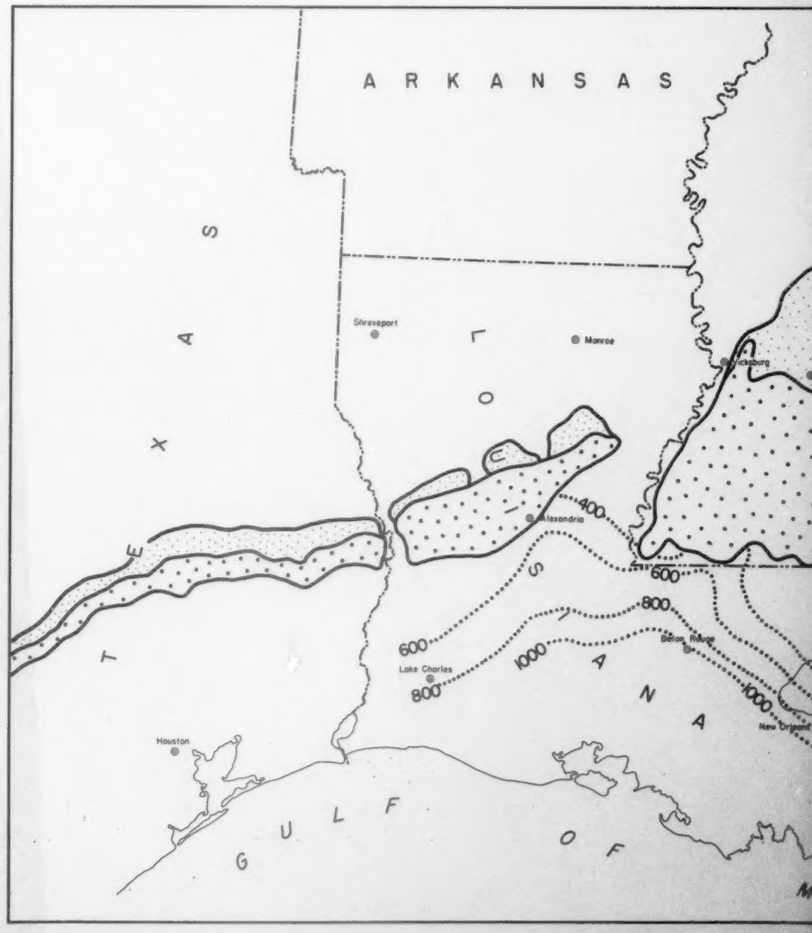


D

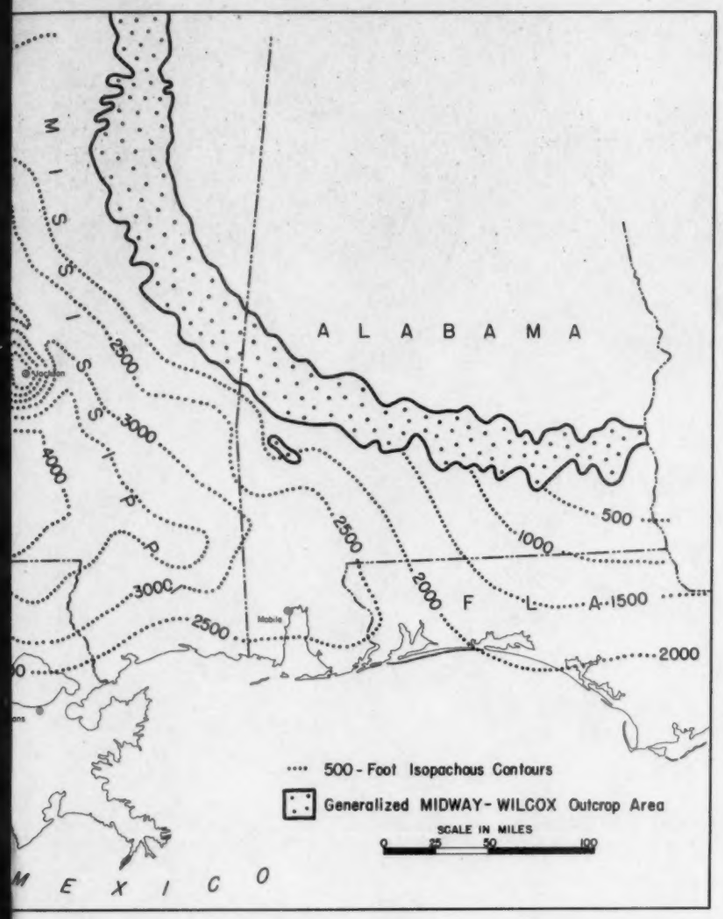
ISOPACHOUS CONTOURS

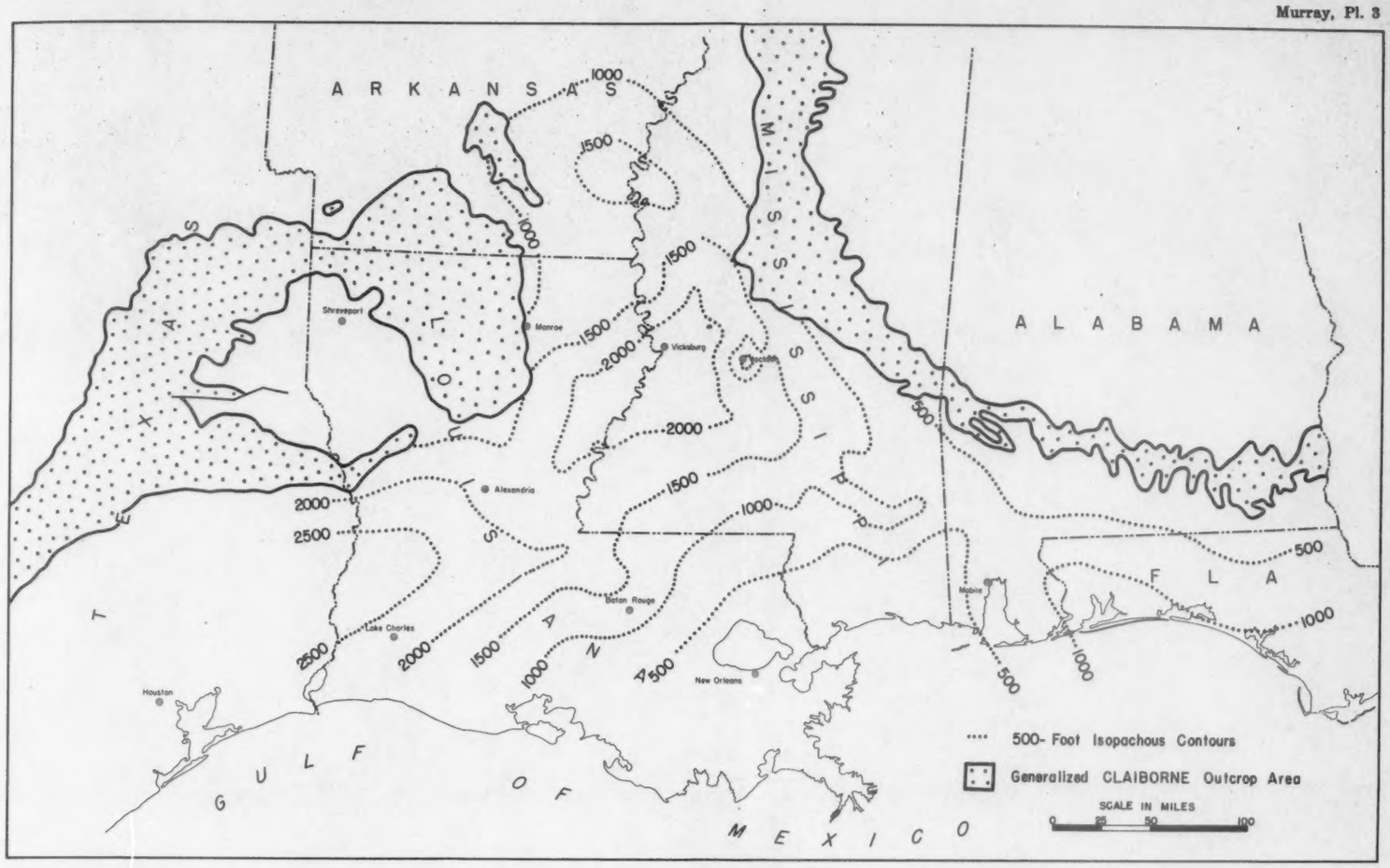
A. ISOPACHOUS CONTOURS OF PALEOCENE (MIDWAY STAGE) - LOWER EOCENE (WILCOX GROUP)

B. ISOPACHOUS CONTOURS OF MIDDLE EOCENE (CLAIBORNE GROUP)

C. ISOPACHOUS CONTOURS OF UPPER EOCENE (JACKSON STAGE) - OLIGOCENE (VICKSBURG STAGE)

D. ISOPACHOUS CONTOURS OF MIOCENE (?) - OLIGOCENE (CHICKASAWHAY) (TOP OF CHICKASAWHAY TO TOP OF VICKSBURG STAGE)





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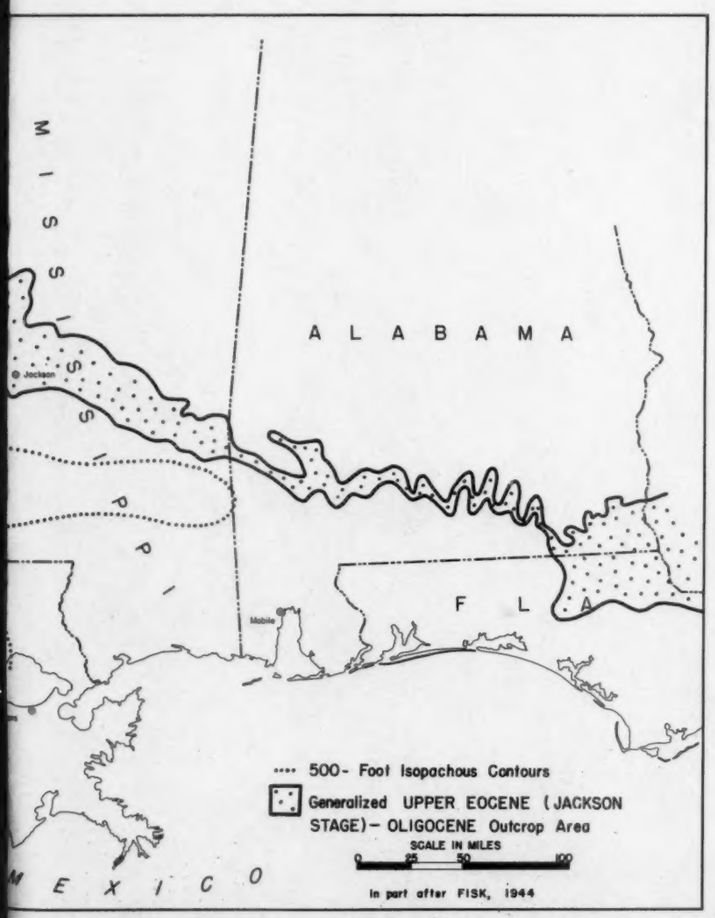

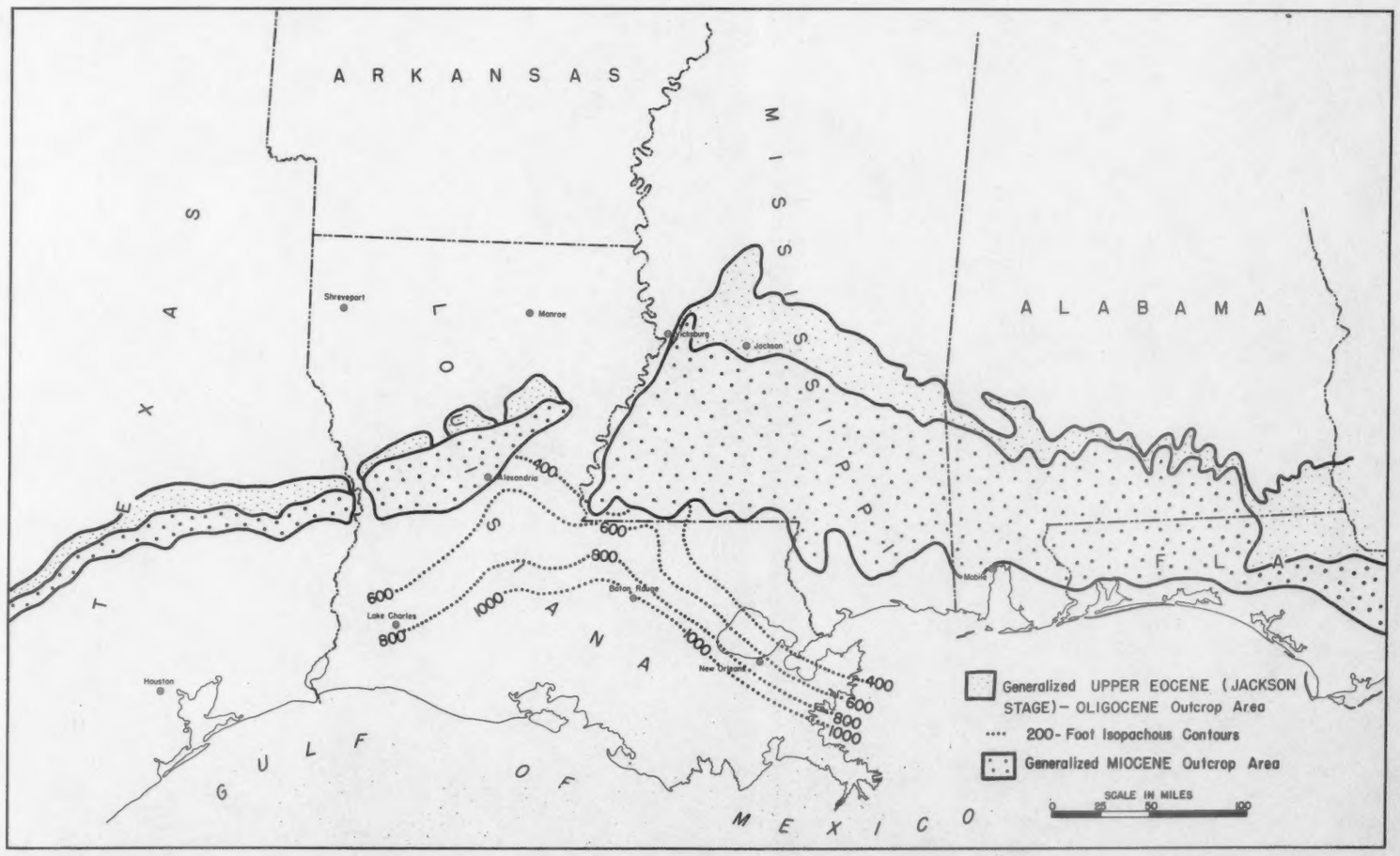

ISOPACHOUS CONTOURS

D

HOUS CONTOURS OF PALEOCENE (MIDWAY STAGE) - EOCENE (WILCOX GROUP)

HOUS CONTOURS OF MIDDLE EOCENE (CLAIBORNE GROUP)

C. ISOPACHOUS CONTOURS OF UPPER EOCENE (JACKSON STAGE) - OLIGOCENE (VICKSBURG STAGE)

D. ISOPACHOUS CONTOURS OF MIOCENE (?) - OLIGOCENE (CHICKASAWHAY) (TOP OF CHICKASAWHAY TO TOP OF VICKSBURG STAGE)

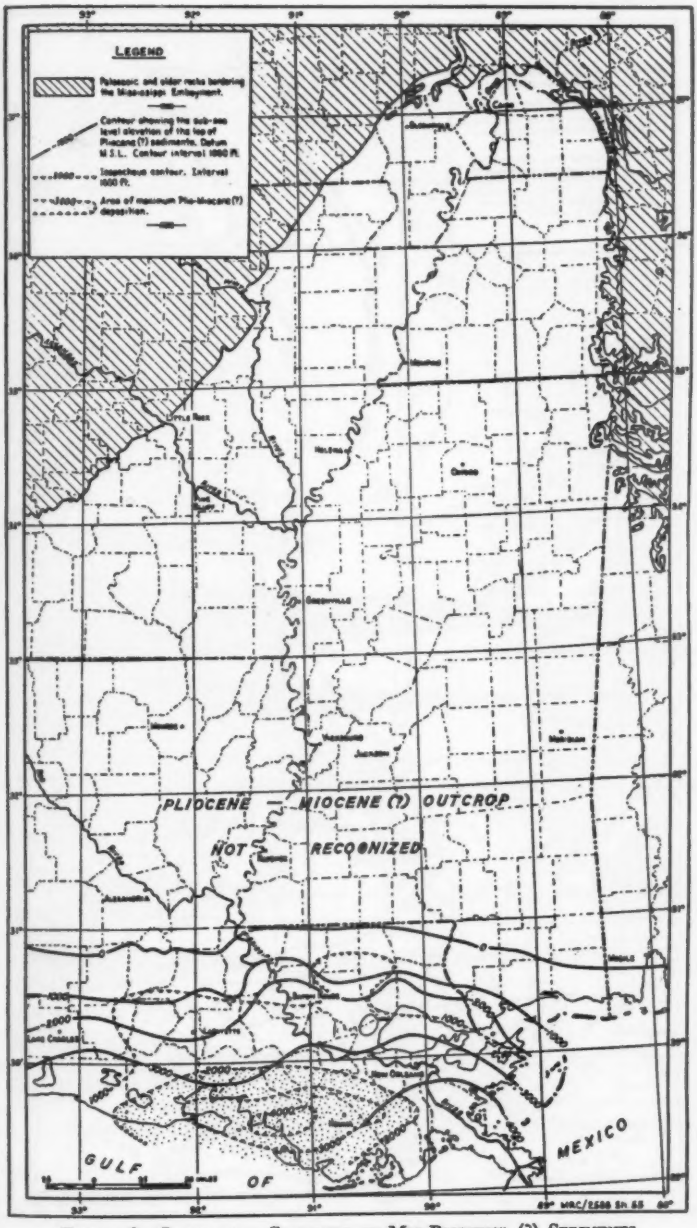

FIGURE 2.—ISOPACHOUS CONTOURS OF MIO-PLIOCENE (?) SEDIMENTS
(Fisk, 1944, Fig. 69)

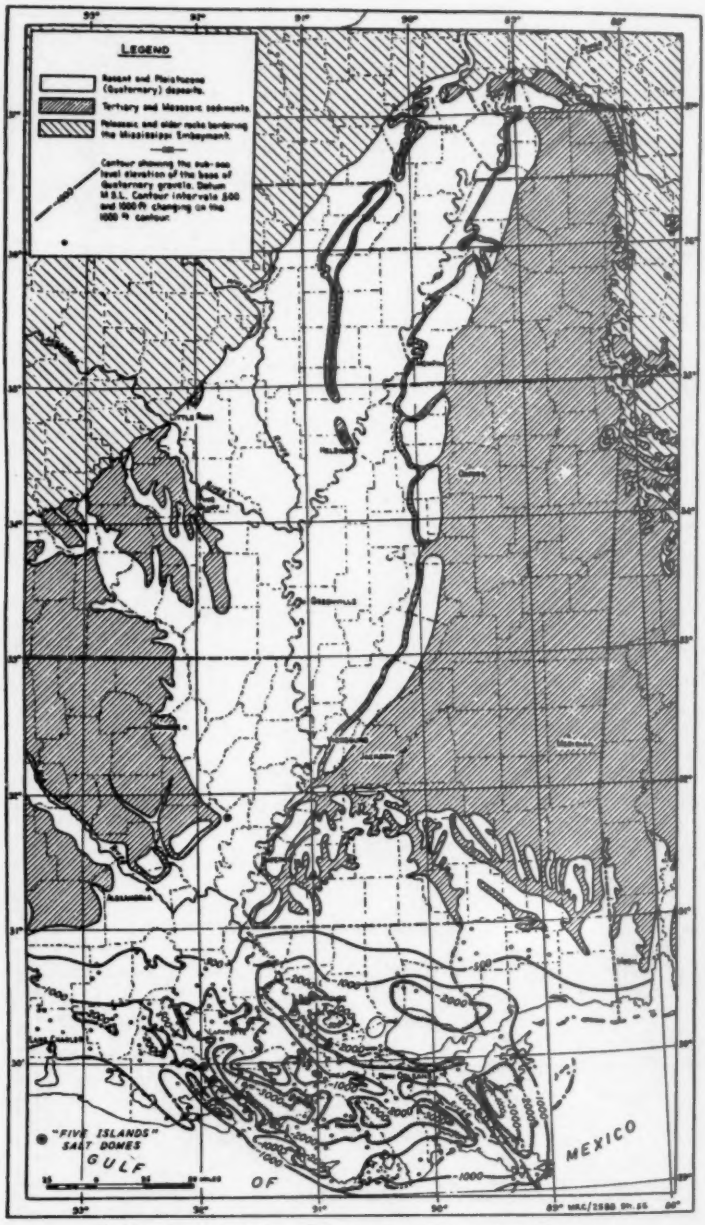

FIGURE 3.—ISOPACHOUS CONTOURS OF QUATERNARY DEPOSITS
(Fisk, 1944, Fig. 70)

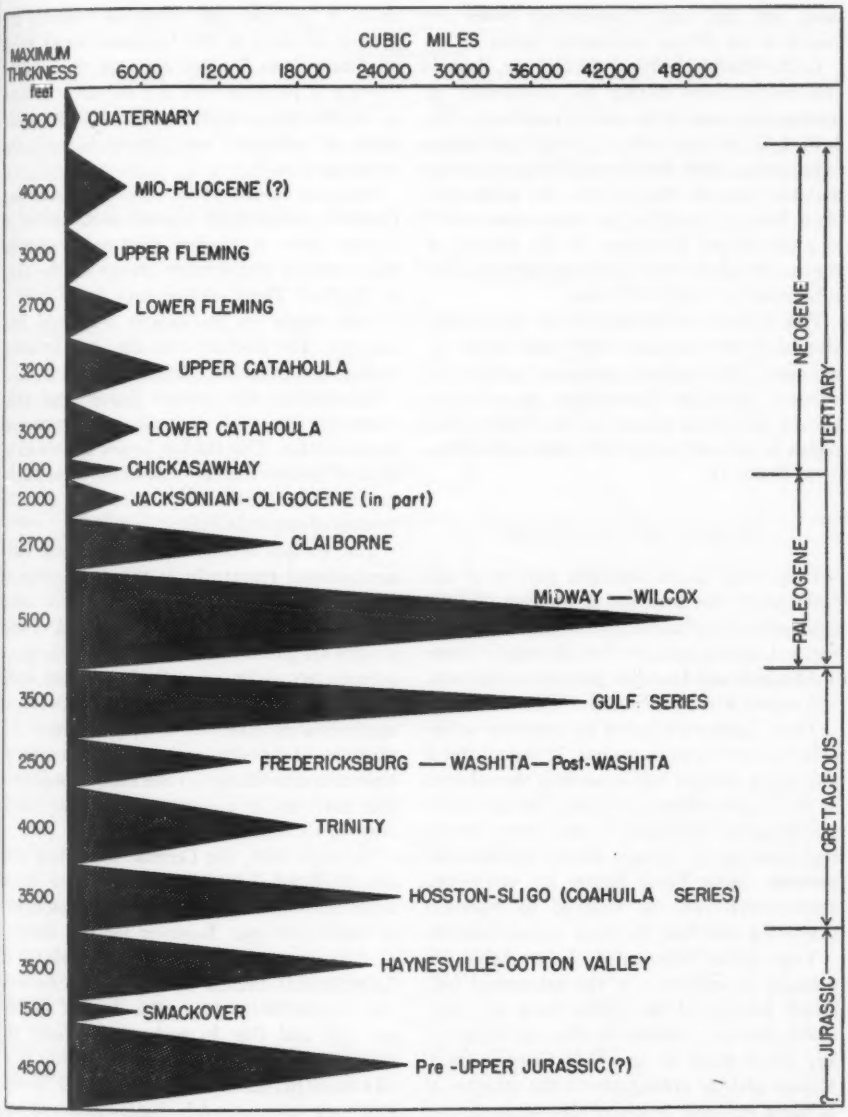

FIGURE 4.—KNOWN MESOZOIC AND CENOZOIC SEDIMENTARY VOLUMES IN EMERGED PORTION OF CENTRAL GULF COASTAL PLAIN

The fluviatile facies occur as terrace deposits flanking the streams and their valleys, and as modern alluvium filling these valleys. Marginal and deltaic facies occur in broad belts essentially parallel to the modern coast line and in the modern coastal marsh; all merge upstream with fluviatile deposits of equivalent age. Marine facies occur in the subsurface.

Lithologically, these deposits consist predominantly of alternating sequences of gravel,

sand, silt, and clay. Fossiliferous lenses are known in the deltaic and marine facies.

In the emerged portion of the plain, deposition concentrated during the Pleistocene in southeastern and south-central Louisiana (Fig. 3; Pl. 4, D). Recent wells in the Gulf of Mexico indicate that 2000–3000 feet of Pleistocene accumulated beneath what is now the submerged plain. Recent deposition has been concentrated in south-central Louisiana in the vicinity of the modern shore. The maximum accumulation is believed to be 600–1000 feet.

Fisk (1944) has estimated the Mississippi alluvial valley contains 1000 cubic miles of sediment. No accurate means of estimating volumes of other Quaternary deposits are known. Minimum volume in the Central Gulf region is believed to be 4500 cubic miles (Figs. 3, 4; Table 1).

Summary and Conclusions

Deep wells in the emerged portion of the plain prove the presence of at least 265,000 cubic miles of sediment. Interpolations based on regional studies indicate that the total volume of Mesozoic and Cenozoic deposits in this area will exceed 300,000 cubic miles (Table 1; Fig 4).

These figures are based on currently available well and subsurface data. It is doubtful if any major changes will be made in the volumes of the larger sedimentary units, though future stratigraphic developments may result in the redistribution of volumes among smaller sedimentary units. These figures are considered conservative and are believed to represent something less than the total volume present.

Very little information is available on volumes of sediments in the submerged (offshore) portion of the plain. Even so, more direct data are available in this region than in any other place in the Gulf Coastal Plain. Recent offshore drilling proves the presence of Miocene strata at depths of approximately 2½ miles. These wells furnish no evidence of any thinning or upturning of strata for at least 30 miles offshore. This alone is sufficient to add about 15,000 cubic miles to the known sedimentary volumes. By interpolation and extrapolation, utilizing well and geophysical data, it is estimated that at least 200,000 cubic miles of Mesozoic and Cenozoic deposits are present offshore. If the basement rocks slope up evenly from 7 miles down at the modern shore to a junction with the continental slope at 10,000 feet, something like 500,000 cubic miles of sediments are present beneath the submerged plain.

Regional studies reveal that Mesozoic and Cenozoic geosynclinal deposits accumulated in arcuate belts of varying thicknesses rimming the northern and western shores of the Gulf of Mexico. These sedimentary belts have a general shape of lenticularly flattened link sausages. The thicker lenses are areas or loci of maximum deposition (depocenters).

Structurally, the arcuate depositional belts represent zones of regional subsidence and accumulation. The thicker lenses appear to be areas of greater than normal subsidence, resulting from concentrated deposition at or near the mouths of major drainages.

The studies reveal, also, that strata have accumulated repeatedly in the depocenters to thicknesses of 3000 feet, more or less, after which the depositional locale shifted. Depocenters are not known to occur vertically above immediately older ones. Such repeated shifts in sedimentary loci, after the accumulation of approximately 3000 feet of strata, suggest this thickness of deposits is related to the maximum load and, accordingly, to the maximum depression that can be accommodated by an elastic crust in a specific area and time.

Through 1949, the Central Gulf Plain area has produced 3,364,238,000 barrels of liquid hydrocarbons and 9,752,090,000,000 cubic feet of marketable gas. Reserves for this area, as of January 1, 1950, were estimated to be 3,500,000,000 barrels of liquid hydrocarbons and 30,000,000,000,000 cubic feet of natural gas (Oil and Gas Journal, 1950; World Oil, 1950). Produced and discovered quantities of oil and gas per cubic mile (cubem) (L. G. Weeks, 1950) are summarized in Tables 2, 3, and 4.

In terms of unit volumes, these figures reveal that the Central Gulf Plain has produced to date 12,500 barrels of oil and 36,000,000 cubic feet of gas per cubic mile. Proven reserves slightly exceed 13,000 barrels and 111,900,000 cubic feet of gas per cubic mile. The total discovered hydrocarbons for the area therefore

TABLE 2.—PRODUCED QUANTITIES OF OIL AND GAS—CENTRAL GULF COASTAL PLAIN

Total produced* (to 1950)	Total sedimentary volume in cubic miles		Approximate production per cubic mile	
	Known	Est.	Known	Est.
3,364,238,000 bbls. of oil	265,000	303,000	12,400 bbls.	11,100 bbls.
9,752,090,000,000 cu. ft. of gas	265,000	303,000	36,000,000 cu. ft.	32,500,000 cu. ft.

*Oil and Gas Journal (1950a; 1950b); World Oil (1950).

TABLE 3.—ESTIMATED RESERVES OF OIL AND GAS—CENTRAL GULF COASTAL PLAIN

Est. Total Reserves (to 1950)*	Total sedimentary volume in cubic miles		Approximate production per cubic mile	
	Known	Est.	Known	Est.
3,500,000,000 bbls.	265,000	303,000	13,200 bbls.	11,500 bbls.
30,000,000,000,000 cu. ft.	265,000	303,000	111,900,000 cu. ft.	99,100,000 cu. ft.

*Oil and Gas Journal (1950a, b); World Oil (1950).

TABLE 4.—TOTAL DISCOVERED HYDROCARBONS (PRODUCED + RESERVES) CENTRAL GULF COASTAL PLAIN

Total Discovered* (to 1950)	Total sedimentary volumes in cubic miles		Approximate production per cubic mile	
	Known	Est.	Known	Est.
6,864,238,000 bbls.	265,000	303,000	25,600 bbls.	22,600 bbls.
39,752,090,000,000 cu. ft.	265,000	303,000	147,900,000 cu. ft.	131,600,000 cu. ft.

*Oil and Gas Journal (1950a; 1950b); World Oil (1950).

TABLE 5.—RATE OF SEDIMENTATION IN EMERGED PORTION OF CENTRAL GULF COASTAL PLAIN

Formations	Duration* in Millions of Years (Approx.)	Maximum thickness of sediments in feet (meters)	Maximum rate of sedimentation		
			Feet per Million Years	Feet per Century	Cm. per Century
Tertiary	60	26,700 (8143)	445	.044	1.4
Neogene (Miocene to Pleistocene)	30	15,900 (4676)	530	.053	1.6
Paleogene (Paleocene to Miocene)	30	10,800 (3176)	360	.036	1.1
Mesozoic (Upper)	55	18,500 (5642) to 23,000 (7005)	336 to 418	.034 to .042	1.0 to 1.3
Cretaceous	40	13,500 (4117)	337	.034	1.0
Upper Jurassic	15	5,000 (1525) to 9,500 (2888)	333 to 633	.033 to .063	1.0 to 1.9
Upper Jurassic to Pleistocene	115	45,200 (13,786) to 49,700 (15,185)	392 to 432	.039 to .043	1.2 to 1.3

*Durations in years after Urry and Holmes (1941) and after compilations by Umbgrove (1947).

approximate 26,000 barrels of oil and 147,900,000 cubic feet of gas per cubic mile of sediment.

The amount of discovered oil per cubic mile (cubem) is below the discovered average of 32,000 barrels for the U. S. cited by L. G. Weeks

(1950) and approximates only half of his estimated ultimate total oil discovery of 50,000 barrels per cubem.

If hydrocarbons are present in similar quantities in the sediments beneath the submerged plain, reserves in that area could be 5–15 billion barrels of oil and 25–75 trillion cubic feet of gas, depending upon the total sedimentary volume in the area. Present drilling and recovery methods would permit commercial exploitation of only a portion of this potential reserve.

The Mesozoic and Cenozoic deposits of the Central Gulf region accumulated during a period of approximately 117 million years. Sedimentary rates, based on maximum known thicknesses, range from 325 feet to 633 feet per million years, or from 0.033 feet to 0.063 feet per century (Table 5).

Jurassic, Comanchean, and lower Gulfian sediments are coarsest in the eastern portion of the Central Gulf. Fluviatile, near-shore deltaic, and marginal sediments are most prominent in this same area. Westward and downdip, finer-grained and calcareous marine facies replace these near-shore or continental sediments. Clastic sedimentation was obviously concentrated in the eastern portion of the area —in Alabama and Mississippi. The lithologic character of the sediments evidences streams of considerable size and ability, and suggests that drainage was well integrated in east-central United States as early as the late Jurassic. Sediments are thought to have come primarily from the interior and highland areas of eastern United States, and from the Appalachian Mountains in particular, during the Jurassic, Coahuilan, Comanchean, and early Gulfian.

After the extensive marine deposition of the middle and late Gulfian and early Tertiary, clastic deltaic deposition prevailed in the Cenozoic throughout most of the emerged Gulf Plain, especially in the Western Gulf Plain. Similar conditions of deposition have continued virtually without interruption to the modern day. The coincidence of this influx of clastic material with the orogenic disturbances referred to as Laramide in the Cordilleran region suggests that middle and western United States have furnished appreciable quantities of sedimentary material to the northern and western shores of the Gulf of Mexico in Cenozoic times. The shape and pattern of the sedimentary masses also suggest that the drainage was well integrated throughout the Cenozoic.

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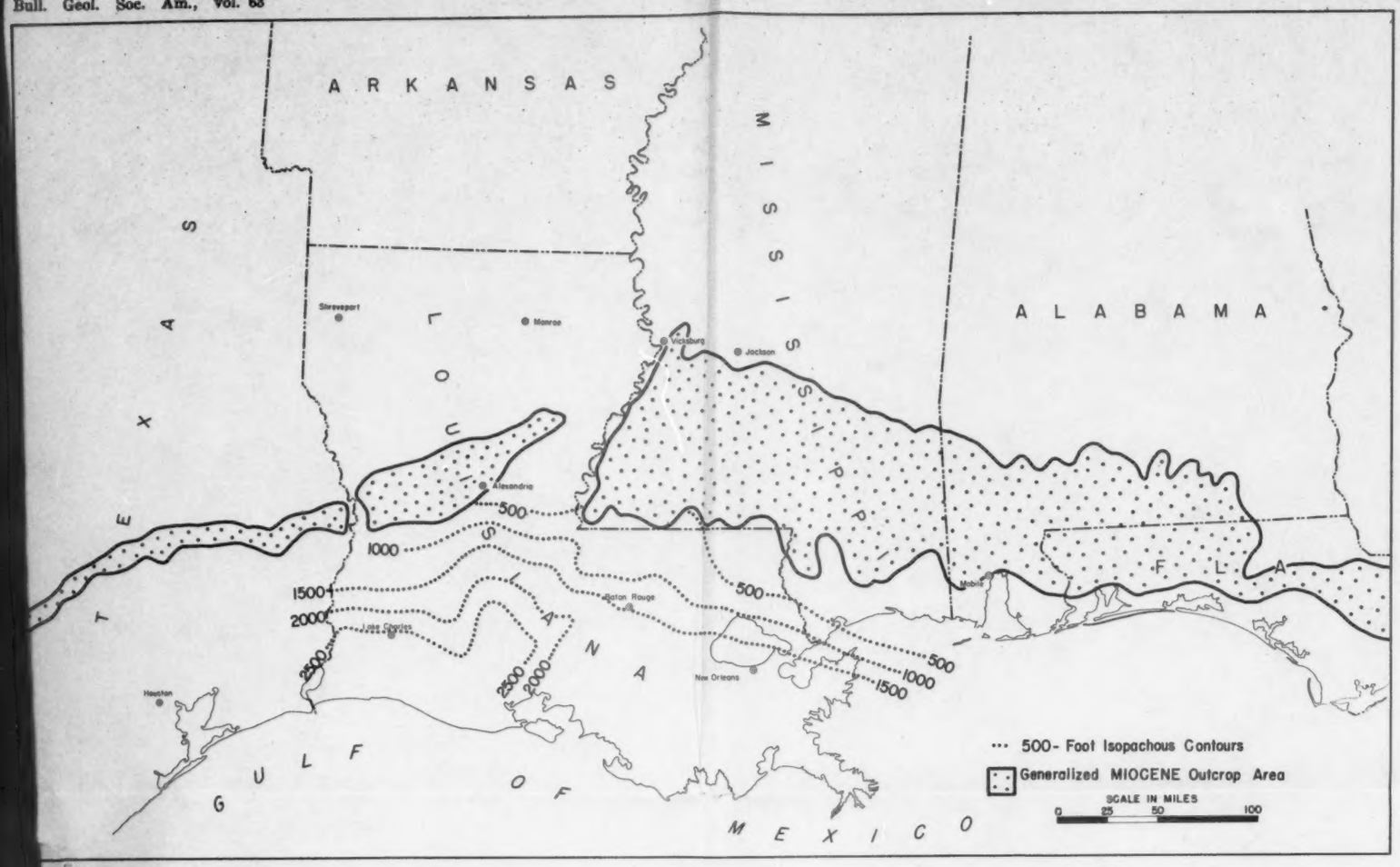

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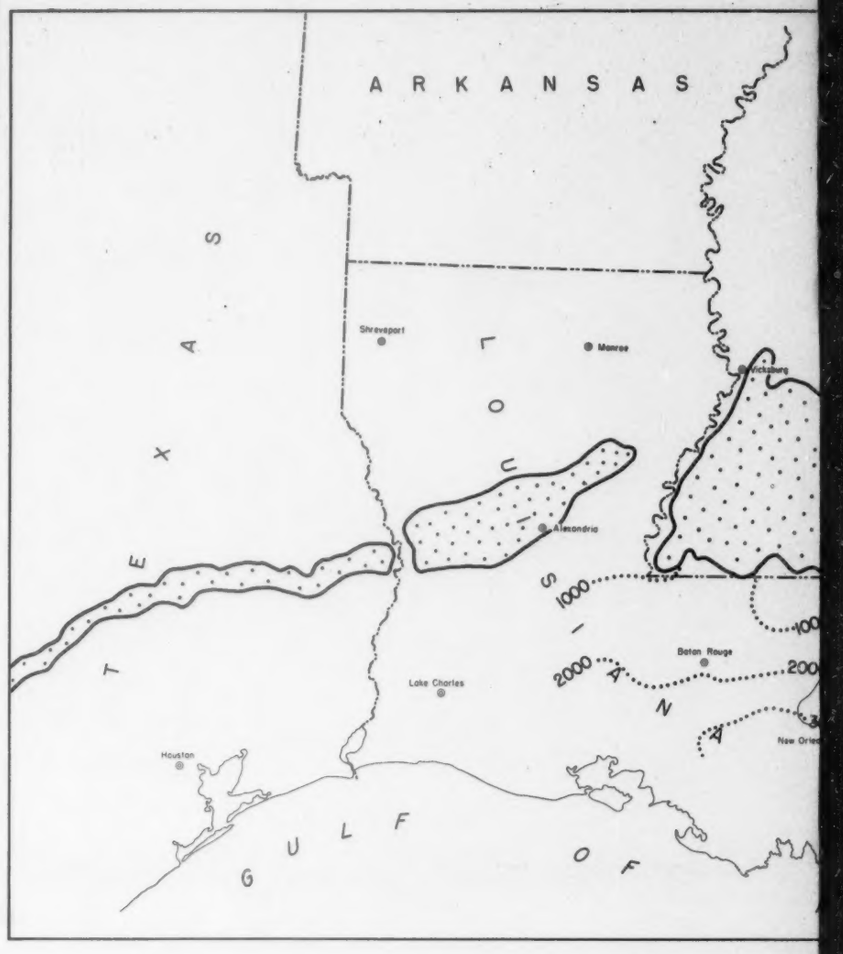

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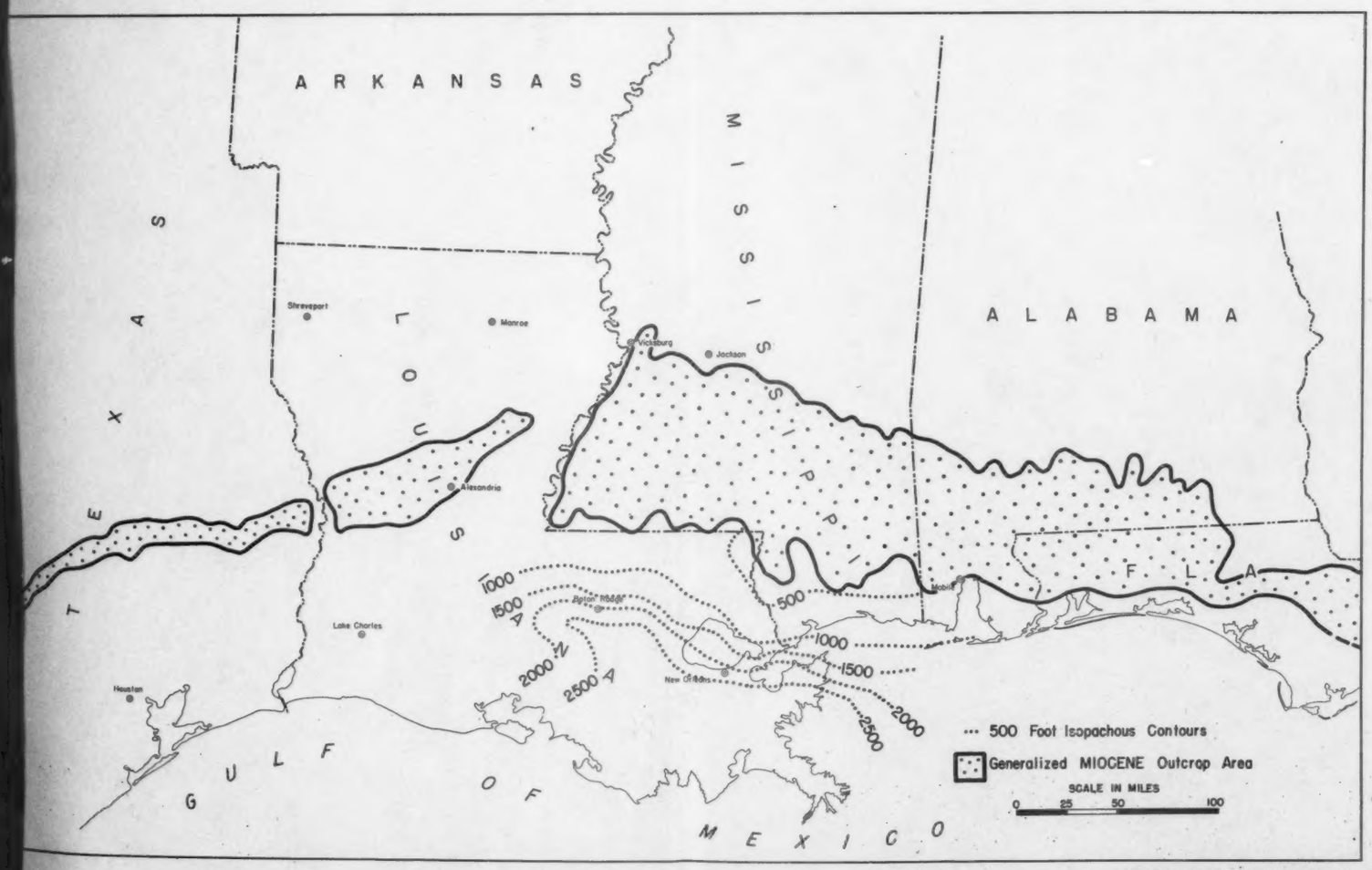

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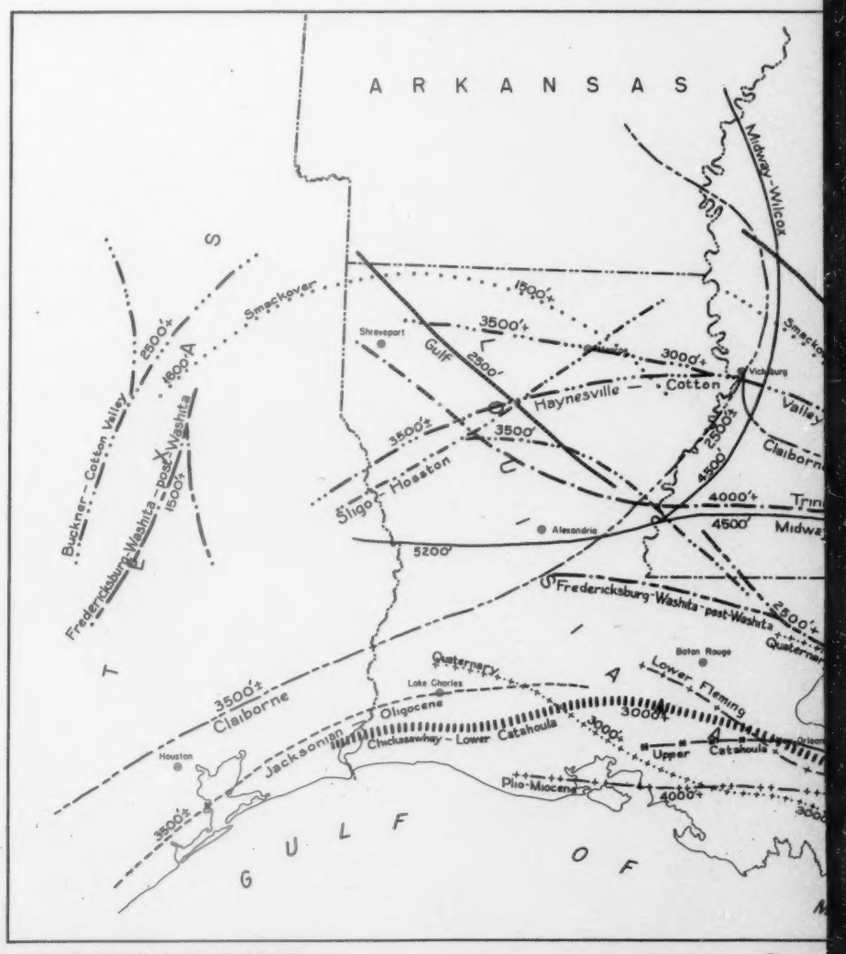

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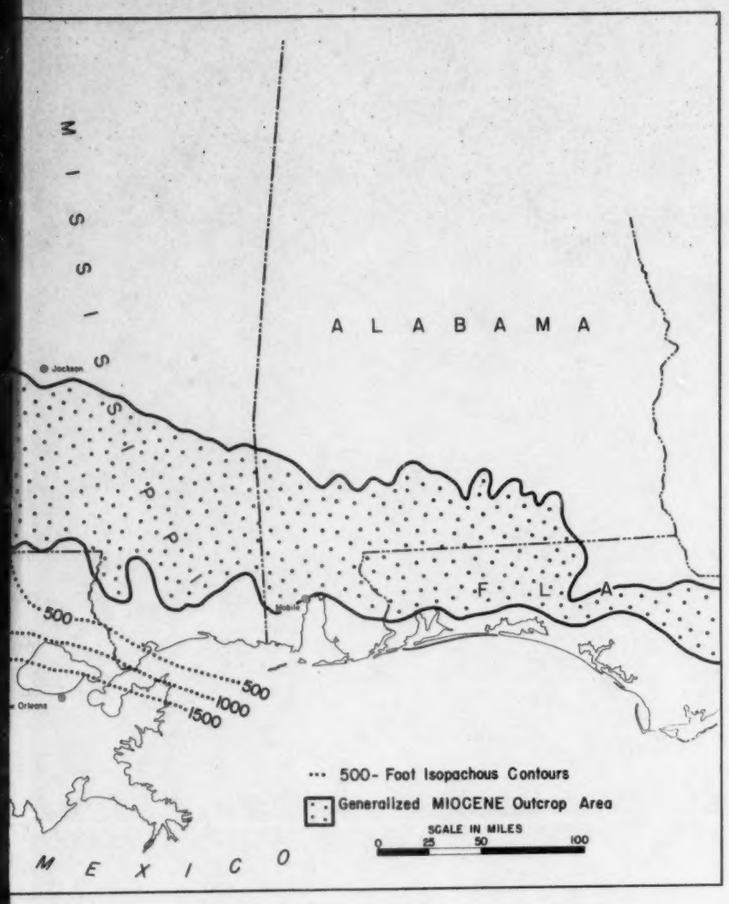
ISOPACHOUS CONTOURS AND DEPOCENTERS

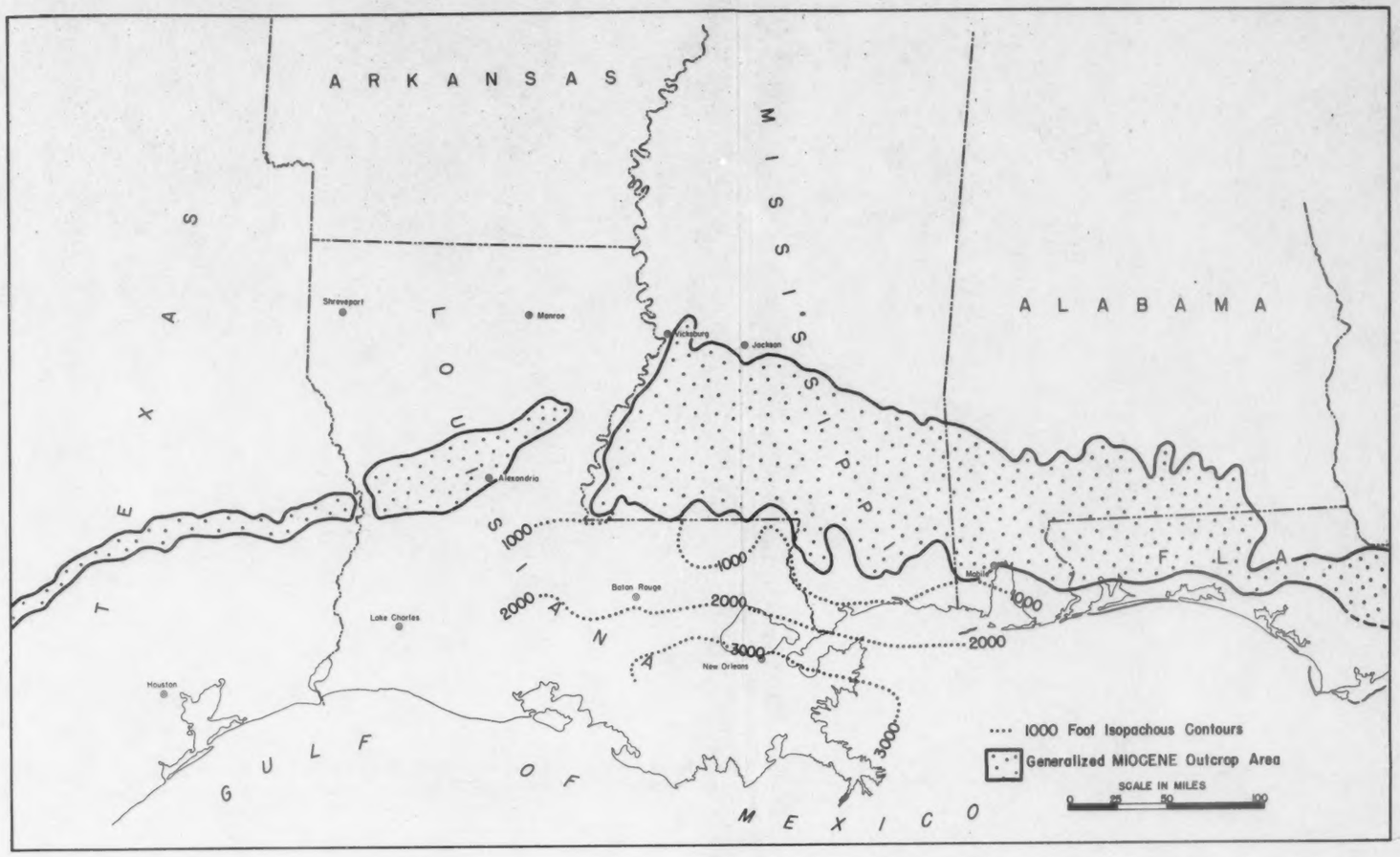
A. ISOPACHOUS CONTOURS OF MIOCENE (LOWER CATAHOULA) (TOP OF *MARGINULINA* ZONE TO TOP OF CHICKASAWHAY)

B. ISOPACHOUS CONTOURS OF MIOCENE (UPPER CATAHOULA) (TOP OF *OPERCULINOIDES* ZONE TO TOP OF *HETEROSTEGINA* ZONE)

C. ISOPACHOUS CONTOURS OF MIOCENE (LOWER FLEMING). TOP OF *POTAMIDES MATSONI* ZONE TO TOP OF *OPERCULINOIDES* ZONE)

D. APPROXIMATE DEPOCENTERS AND AXES OF MAXIMUM DEPOSITIO CENTRAL GULF COASTAL PLAIN





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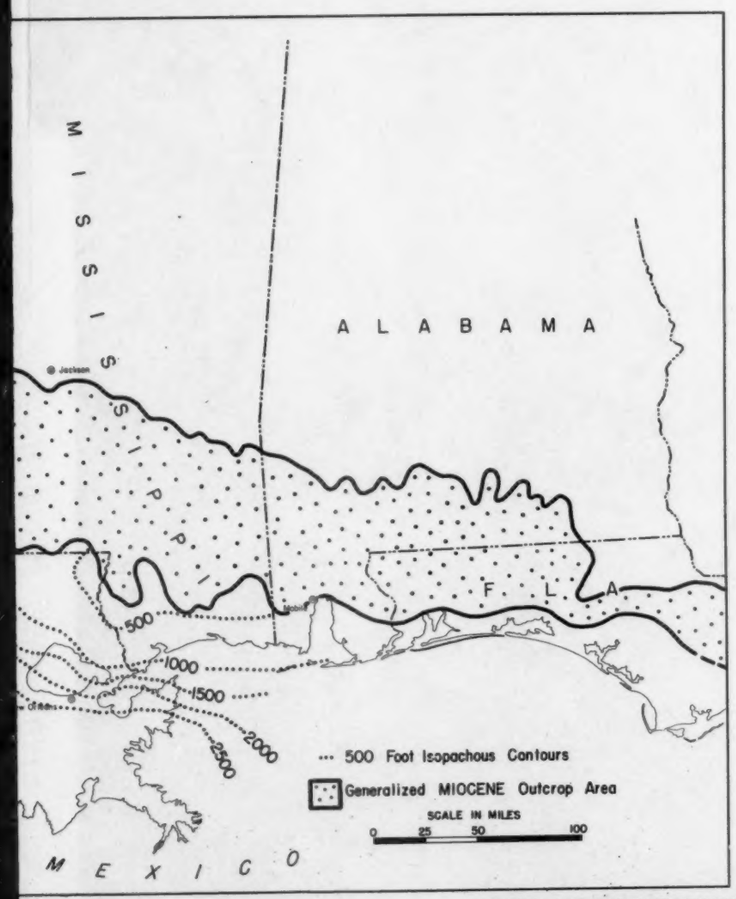

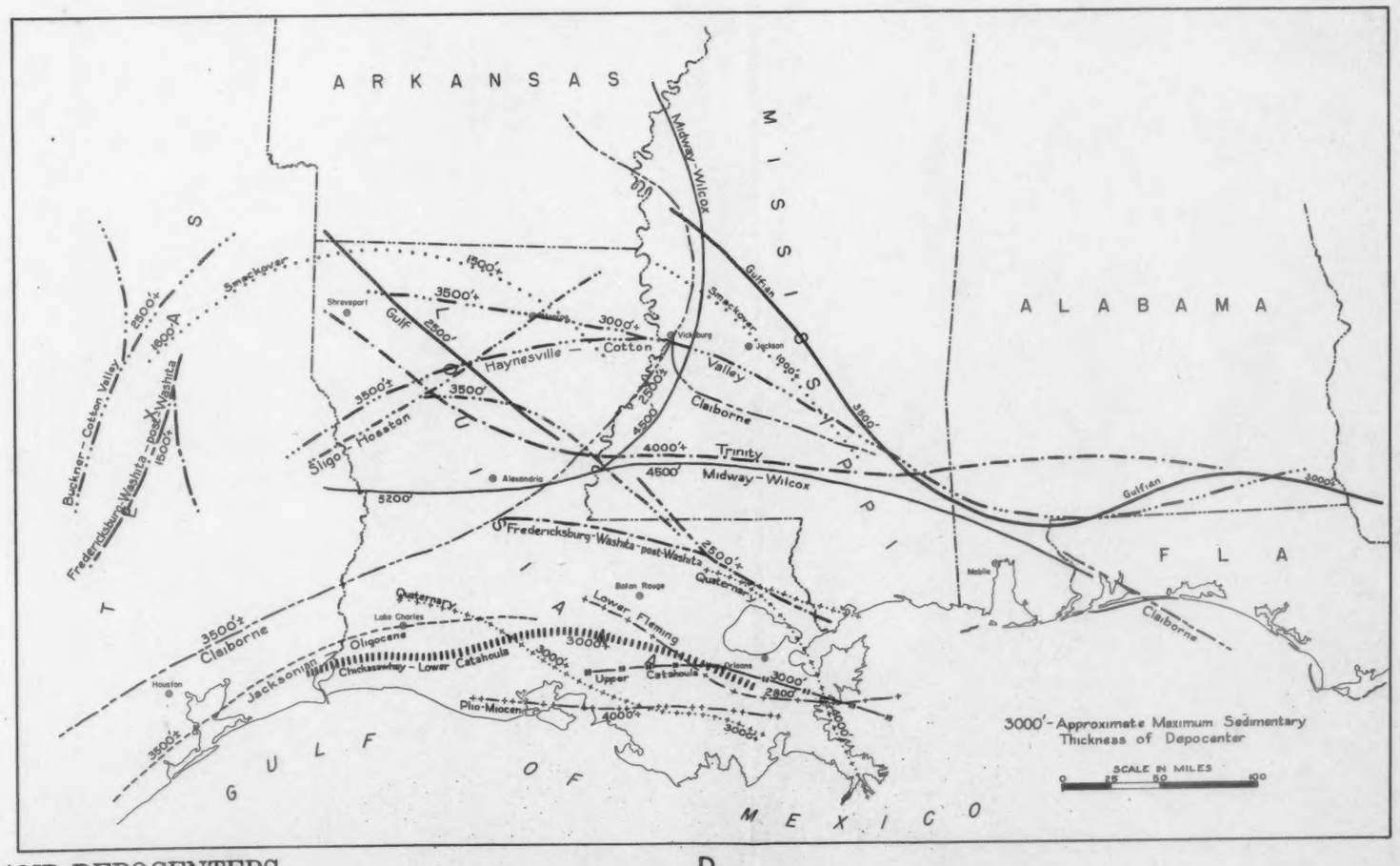

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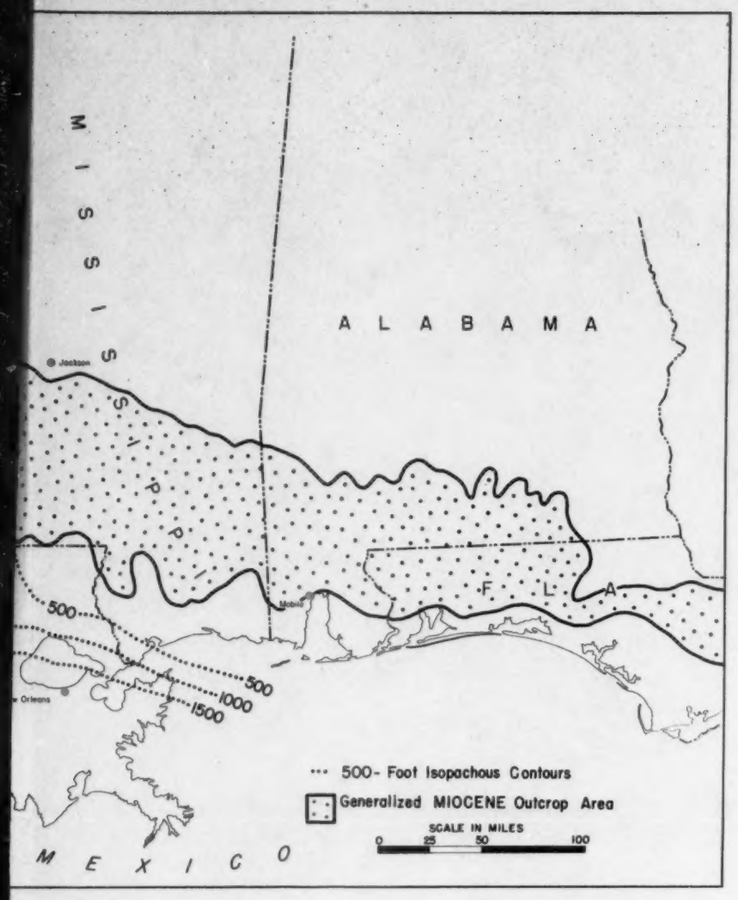

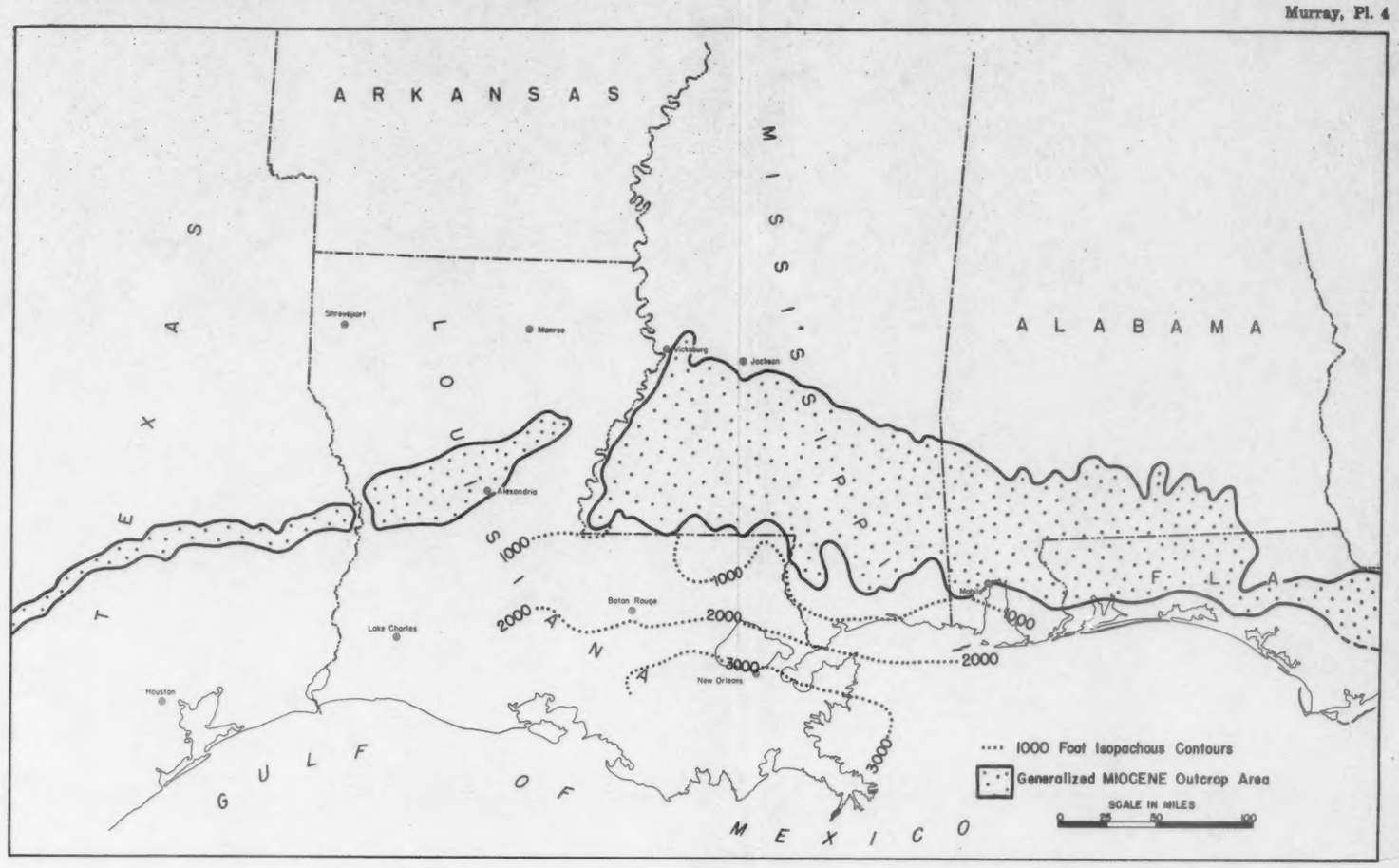

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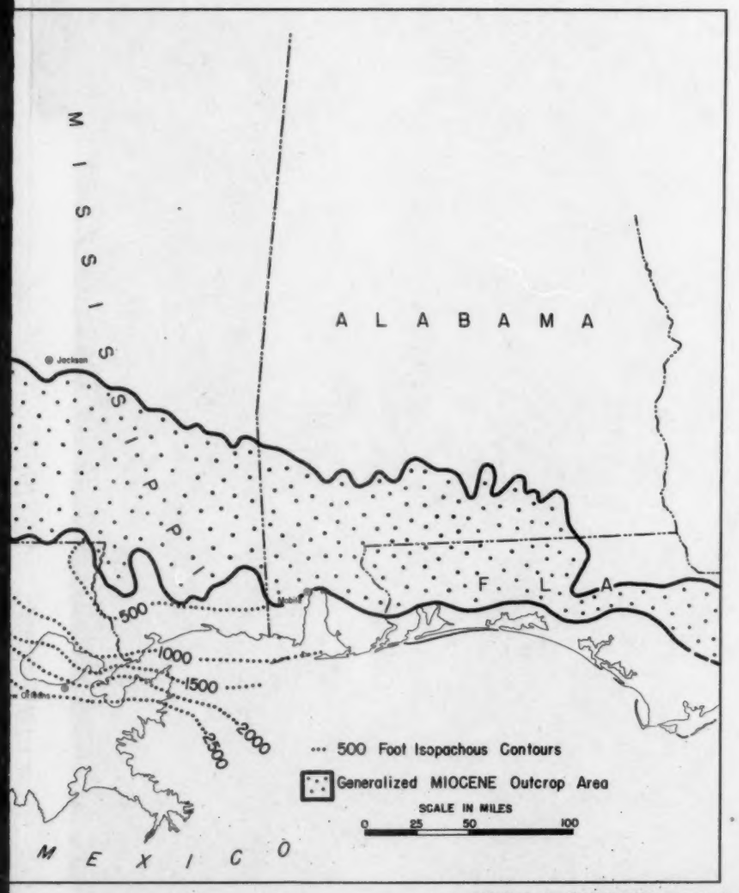

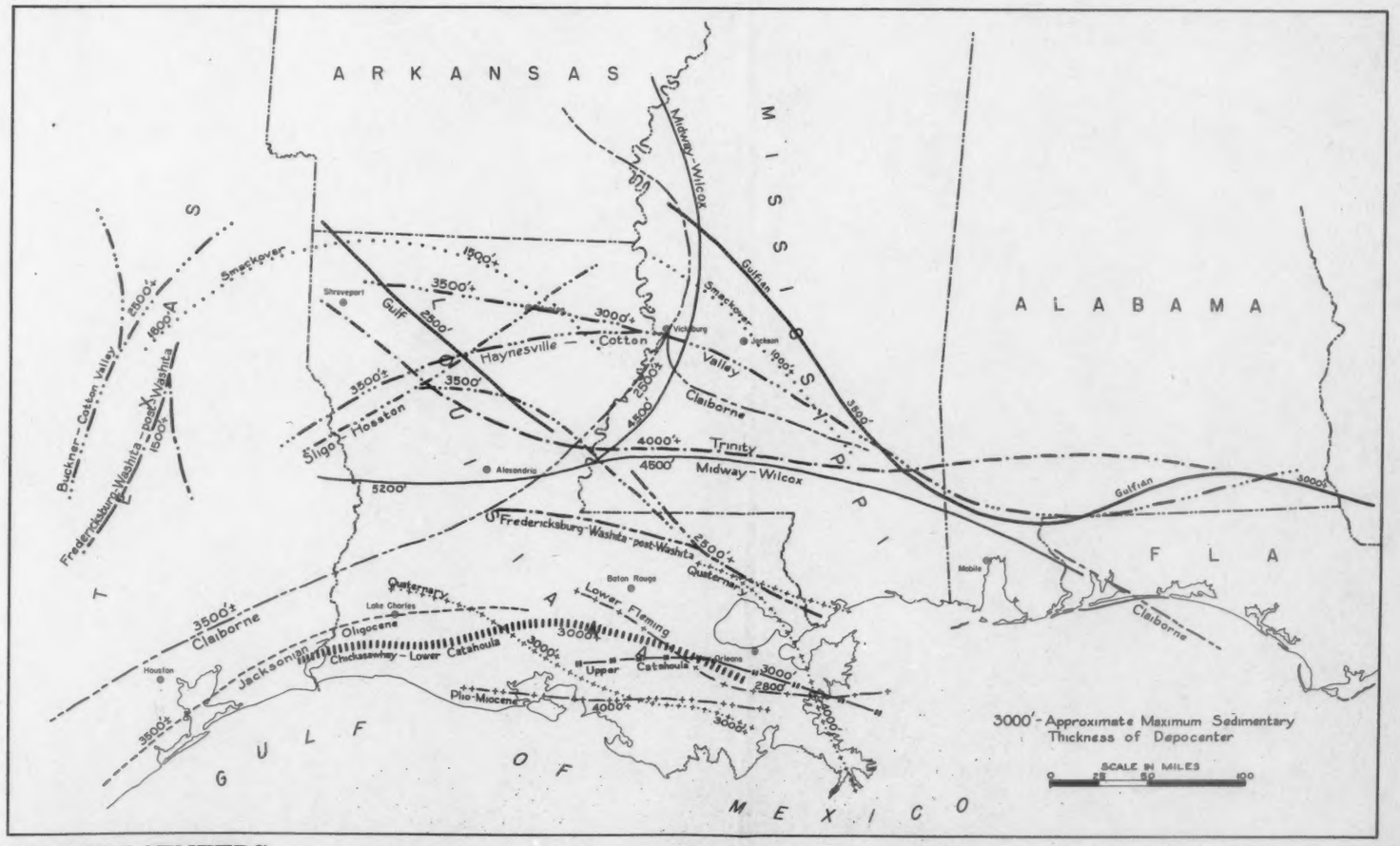

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SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF UNITED STATES AND MEXICO

PART IV: VOLUME OF MESOZOIC AND CENOZOIC SEDIMENTS IN WESTERN GULF COASTAL PLAIN OF UNITED STATES

BY JACK COLLE, W. F. COOKE, JR., R. L. DENHAM, H. C. FERGUSON, J. H. MCGUIRT, FRANK REEDY, JR., AND PAUL WEAVER

(*Houston Geological Society, Committee on Sedimentation*)

ABSTRACT

The Western Gulf Coastal Plain of the United States lies entirely in the State of Texas. Underlying it and under the portion of the continental shelf in front of it, Mesozoic and Cenozoic sediments dip generally toward the present Gulf of Mexico.

Considerable control from subsurface information to a depth of about 2 miles has been used to construct subsurface and isopachous maps both of formations which outcrop and of others of substantial thickness known in this area only from subsurface data. From these maps, the volume of sediments of different ages was calculated.

The calculated volumes are 453,000 cubic miles under the land area of 90,000 square miles and 271,000 cubic miles under the continental shelf area of 29,000 square miles. The total volume therefore of Mesozoic and Cenozoic sediments is 724,000 cubic miles, representing a mean thickness of about 6 miles.

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INTRODUCTION

The Western Gulf Coastal Plain of the United States comprises a land portion entirely in the State of Texas and a portion of the continental shelf of the Gulf of Mexico which lies offshore from Texas.

The coastal plain of Texas inland from the Gulf of Mexico has been studied for many years in surface outcrops, and it has also been explored by the study of samples from wells. No portion of the Gulf Coastal Plain has a greater density of wells, and many of them are more than 2 miles deep.

But even this wealth of data is not adequate for a precise calculation of the prism of the Mesozoic and Cenozoic sediments, because over wide areas, some of these sediments are at depths of more than 10,000 feet, so that they have not been penetrated completely by the deepest wells. Combining partial geologic

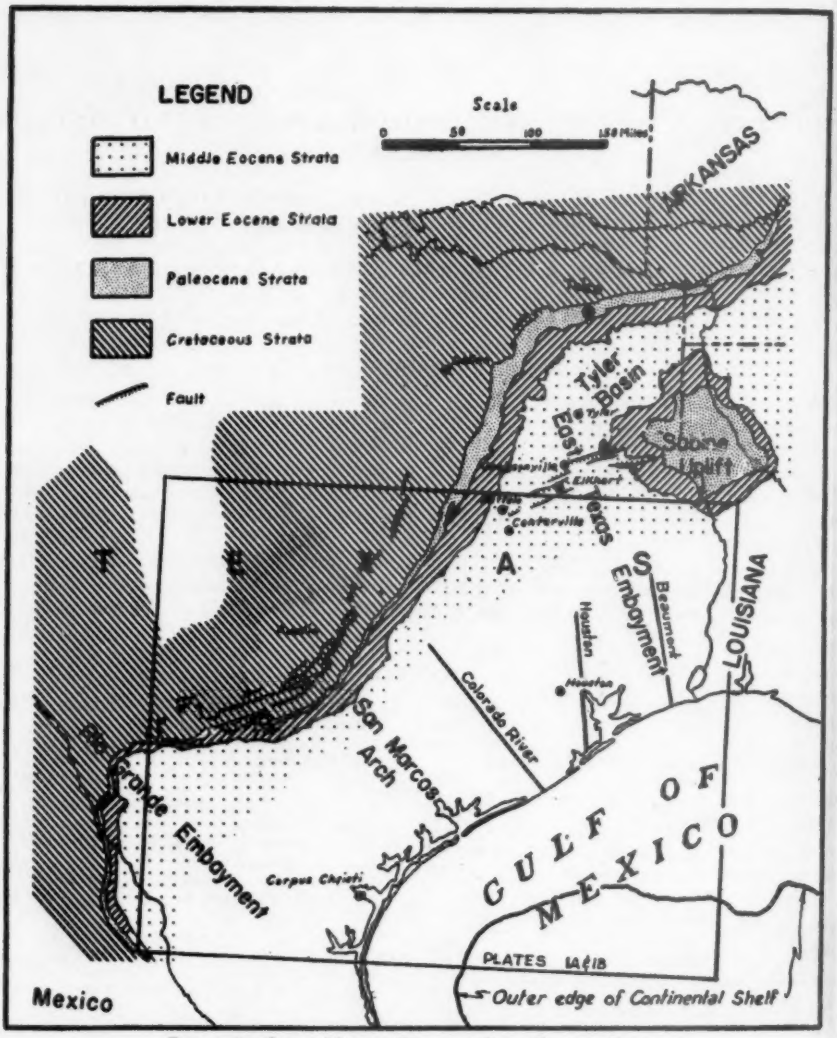


FIGURE 1.—INDEX MAP OF WESTERN GULF COASTAL PLAIN

sections from near-by areas, it is reasonable to infer total sections of the order of 30,000 feet of the combined Mesozoic and Cenozoic column under large areas.

These same sediments are believed to be present also under the continental shelf of the Gulf of Mexico. Some geophysical structural mapping together with a small amount of well data indicate that geological conditions on land are maintained seaward from the coast line and therefore that thicknesses of the Mesozoic and Cenozoic formations under the continental shelf are also of the same great order of magnitude.

In the absence, within the province, of complete distribution of outcrops and wells which can be sampled, estimation of sedimentary volumes requires that the known data be extra-

polated both laterally and vertically downward. This extrapolation can be done with confidence because of the rather simple geologic history of the province as a whole.

In order that the reader may visualize the scope of the sediments under discussion, the final results are taken from Table 1: Total volumes of Mesozoic and Cenozoic sediments are estimated to be 453,000 cubic miles under the land area of 90,000 square miles, and 271,000 cubic miles under the continental area of 29,000 square miles; the total volume therefore is 724,000 cubic miles—a mean thickness of about 6 miles.

Description of the Province Defined as the Western Gulf Coastal Plain

For this discussion, the Western Gulf Coastal Plain is defined as including both a land area and a portion of the continental shelf (Fig. 1).

The land area begins at the coast line of the Gulf of Mexico and extends inland in the State of Texas to the outcrop of the highest bed of the Gulf Cretaceous. The interior limit thus defined is a line which runs across the State from the northeast corner, first westerly, then southwesterly, and finally again westerly to the Rio Grande which bounds the Republic of Mexico. This interior limit corresponds closely to the most easterly fault of the Balcones system. It also approximates the position of the most easterly wells which have encountered the buried sediments of the Ouachita facies.

The continental shelf within this province is defined as the submerged area of the Gulf of Mexico from the coast line to the 200-meter depth line, and bounded by projections of the land boundaries of the State of Texas into the Gulf of Mexico normal to the coast line.

General Geology

The Geologic Map of Texas and the Structural Map of Texas, together with the Tectonic Map of the United States, show that in the land portion of the Western Gulf Coastal Plain, as defined above, the outcropping formations dip toward the coast, as do the subsurface contours, with the exception of several major features:

(1) The East Texas Embayment and its continuation, the Tyler Basin. In the deeper subsurface, these are much restricted in area to form a smaller basin, near the town of Tyler, with a north-south axis.
(2) The Sabine Uplift, east of the deeper Tyler Basin, and extending into Louisiana.
(3) The San Marcos Arch; much thinning of Mesozoic formations, but little or no movement during Cenozoic.
(4) The Rio Grande Embayment.

The formations which outcrop within and immediately west of the Western Gulf Coastal Plain (Fig. 1) generally maintain their surface lithologic facies to as great depth as they have been drilled, except that several of the sandy ones are losing the coarser sand members toward the coast. Some of these formations, however, change in thickness toward the coast.

Even more significant a geologic factor in the change of overall thickness of the combined Mesozoic and Cenozoic toward the coast is the presence of beds in the subsurface which have no outcrop equivalent near by.

Special Structural Features

These two factors—change in thickness down dip and existence in the subsurface of beds not present on the outcrop—are important geologic features of the geology of the Western Gulf Coastal region. They have not hitherto been summarized in the literature, because data are still lacking to localize them in every part of the province.

Deeper subsurface contouring than that on the third edition of the Structural Map of Texas (Sellards and Hendricks, 1946) shows the following characteristics of thickness for the formations down-dip, both those which can be followed into the subsurface from their outcrops and those known only from the subsurface:

(1) Some formations show no substantial thickening down-dip—*i.e.*, toward the present Gulf of Mexico.
(2) There is no suggestion of thinning of any group in a southern or eastern direction to the greatest depth thus far

explored, and there is evidence that many of them thicken down-dip.

(3) This thickening of formations down-dip is not progressively greater in a regular way across the province, but is accentuated in definite geographic belts and at specific periods.

Such belts form zones which extend essentially all the way across the province and are approximately parallel, the oldest inland, the youngest near the coast line. Each zone shows accentuated dip of the older formations and a thickening of the immediately succeeding younger formation on the coastward side of the zone. These zones where data of downwarp have been studied may represent great step faults at still greater depths, but the accumulated evidence suggests that they represent accentuated tilting toward the sea. In succeeding paragraphs they will be called "flexures," for convenience. At these flexures, the major changes of thickness occurred.

Location and Magnitude of Flexures

The earliest flexure which affects these sediments carried the Paleozoic floor to a great depth within a short distance, thereby providing, on its coastward side, the basin in which thick Jurassic beds were deposited above the Louann salt. These Jurassic beds are the oldest included in this calculation.

No Jurassic crops out near by, and the total information concerning its thickness is derived from a relatively few localities near its former shore line, because its dip is steep, and the top of the Jurassic at its shallowest depth is 5000 feet below the present surface.

This flexure is parallel to and 15–25 miles coastward from the interior boundary of the Western Gulf Coastal Plain. The Jurassic thickens from zero to more than 2000 feet at the rate of about 500 feet per mile at one locality, and seismic data with limited well data suggests that this rate is generally more than 250 feet per mile close to the flexure.

The Jurassic presently known from wells is similar to equivalent beds in Arkansas, and its thickening involves clastics and salt, as well as anhydrite and limestone.

The second flexure is in nearly the same location, but locally is possibly as much as 20 miles farther inland. It therefore is about on the interior boundary of the Western Gulf Coastal Plain. It also resulted in a basin on its coastal side in which beds were deposited which are roughly equivalent to the Torcer and Las Vegas of far West Texas but have no outcrop equivalent near the area under discussion. This flexure thickens the Hosston and Sligo of the subsurface about 1500 feet in some 10 miles down-dip. Data are lacking as to total amount of thickening.

After this flexure as an episode in the initial Cretaceous, there appears to have been quite regular deposition in the area where the late Comanchean formations have been reached by wells. The beds seem to be similar in lithology and thickness to the equivalent beds on the surface near by. Total thickness of the beds ranges regionally from 2000 to 3000 feet.

Gulf Cretaceous is not variable down-dip as compared to the outcrop except that clastic members may be changing to shale, but down-dip data below 10,000 feet depth are few.

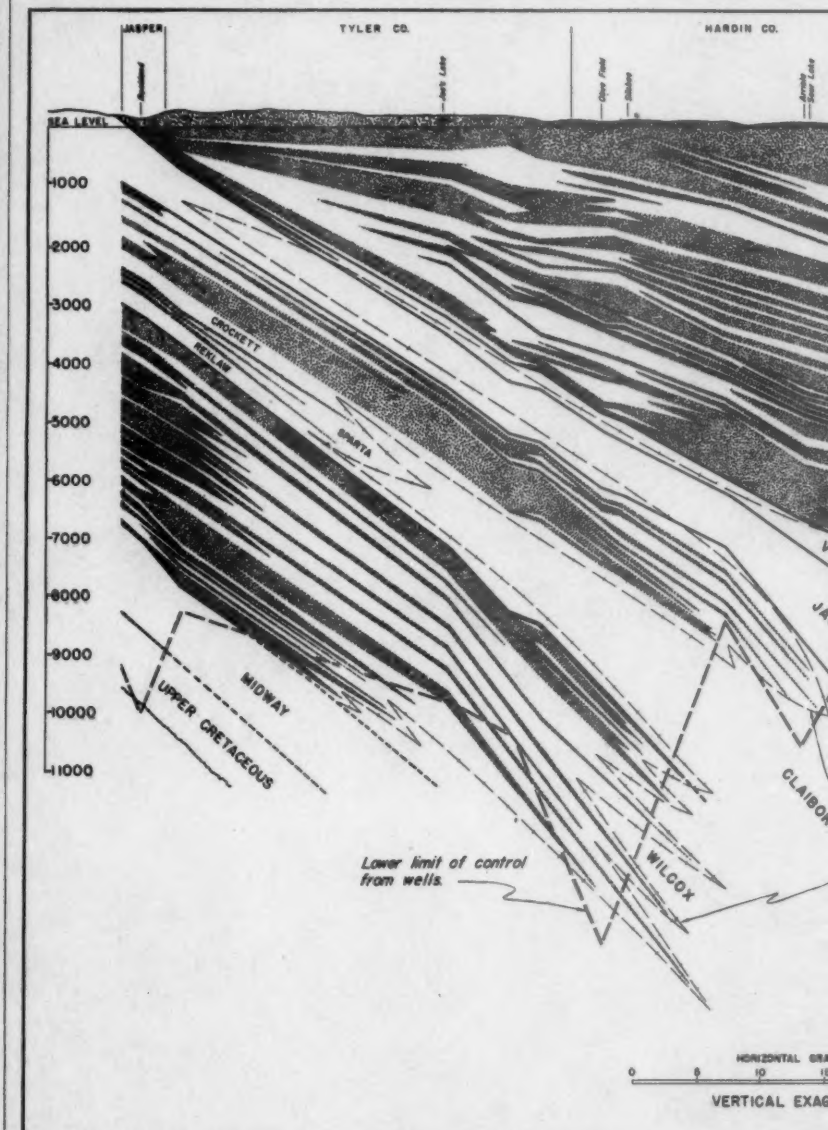
Similar lack of variation from the outcrop to the subsurface is true also for the lower part of the Paleocene-Eocene, and the Midway group seems especially constant in thickness down, so far as explored.

The third flexure (Fig. 2; Pls. 1, 2, 3) is manifest primarily by a tremendous thickening of the Wilcox (Eocene) and to a lesser extent by thickening of the next succeeding Reklaw (lower Claiborne), prominent where the Claiborne changes from mostly nonmarine to mostly marine.

This flexure is about half way to the coast from the first and second flexures. It increases the thickness as far down-dip as the deepest wells drilled, but toward the eastern part of the province the deeper wells show a change with depth from sandstone to silt and shale. Nearer the flexure—*i.e.* inland—the increased thickness is mostly sandstone, as is the Wilcox on the outcrop.

The total thickening cannot be obtained far down-dip because wells in appropriate location are not deep enough, but it is at least 5000 feet.

The fourth flexure has been discussed in the literature as the "Vicksburg" flexure, but should



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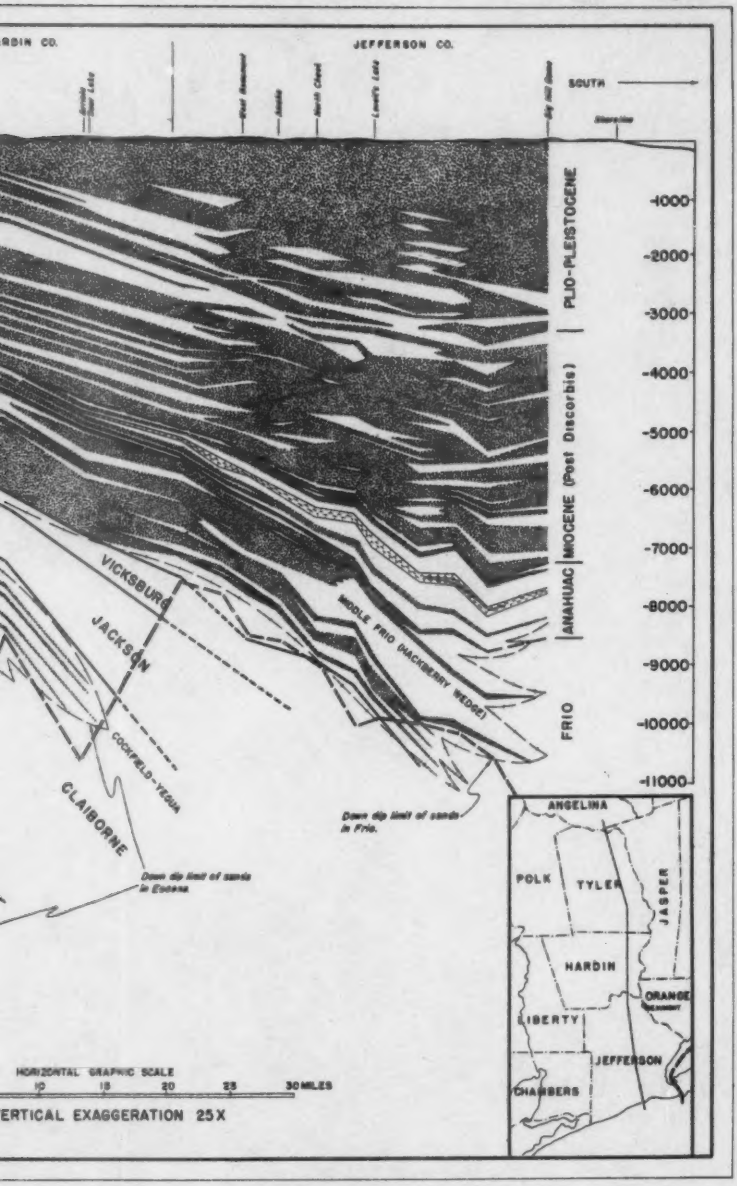

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be dated as post-Vicksburg, and represents a thickening which corresponds essentially to the Catahoula flexure in Louisiana. It not only causes thickening of the post-Vicksburg, but is associated with a further structural development represented by several large elongated anticlines on which Vicksburg beds are high and post-Vicksburg beds have a locally shortened section. At the southern end of the flexure, downwarping seems to be accompanied by faulting of the order of 3000 feet.

In the general area of this flexure are many salt domes in the Houston territory, and there are also numerous faults, generally downthrown to the coast, against which oil and gas have accumulated.

The magnitude of the thickening on the coastward side of this flexure is evidenced by Figure 3, an isopachous map from the Discorbis zone (top of "Marine Oligocene Shale" of Plates 2 and 3) down to the Vicksburg, and the thickening is comparable to the thickening of the Catahoula in Louisiana. There are few wells in Texas as a control for calculating the total thickening because most of the oil and gas have been obtained from the top of this prism in Texas, but in Louisiana there are more well data through the section.

There is evidence near the coast line in Texas that the sands are fewer and thinner in the upper part of the thickened section, but in the same position there has developed a thick marine wedge shown on Plates 2 and 3 as "Marine Oligocene Shale", so that the present

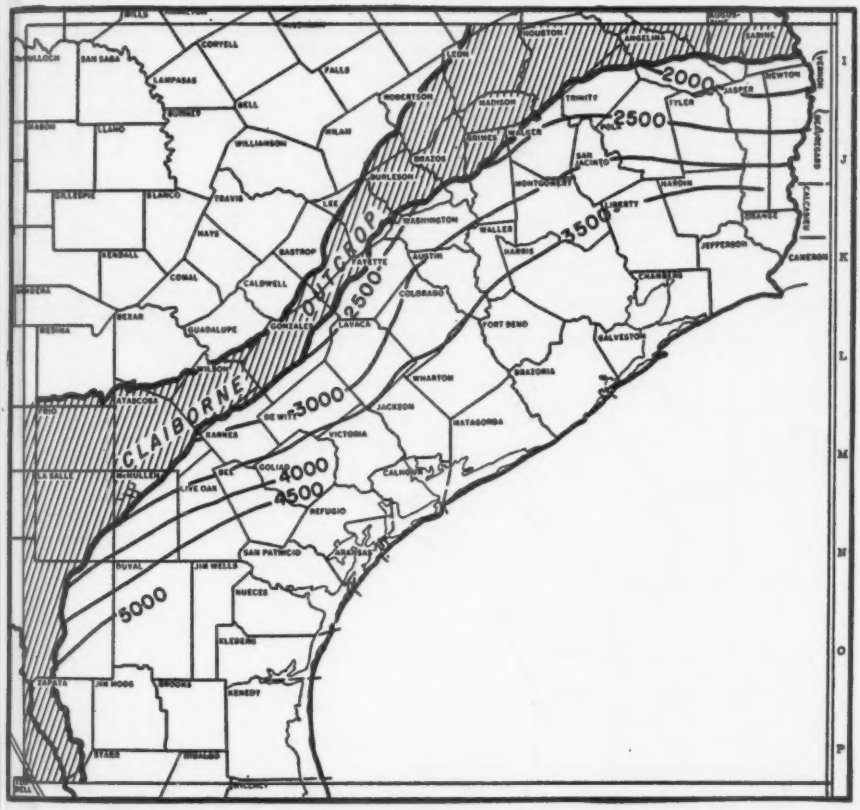


FIGURE 2.—ISOPACH MAP OF INTERVAL FROM TOP OF CLAIBORNE TO TOP OF WILCOX

data to the seaward limit of wells suggest that the section is still thickening.

The fifth flexure is along the coast line and shows thickening of the post-Discorbis Miocene and Pliocene, but there are few wells to give the stratigraphic column in the detail that is so well known in adjacent areas in Louisiana.

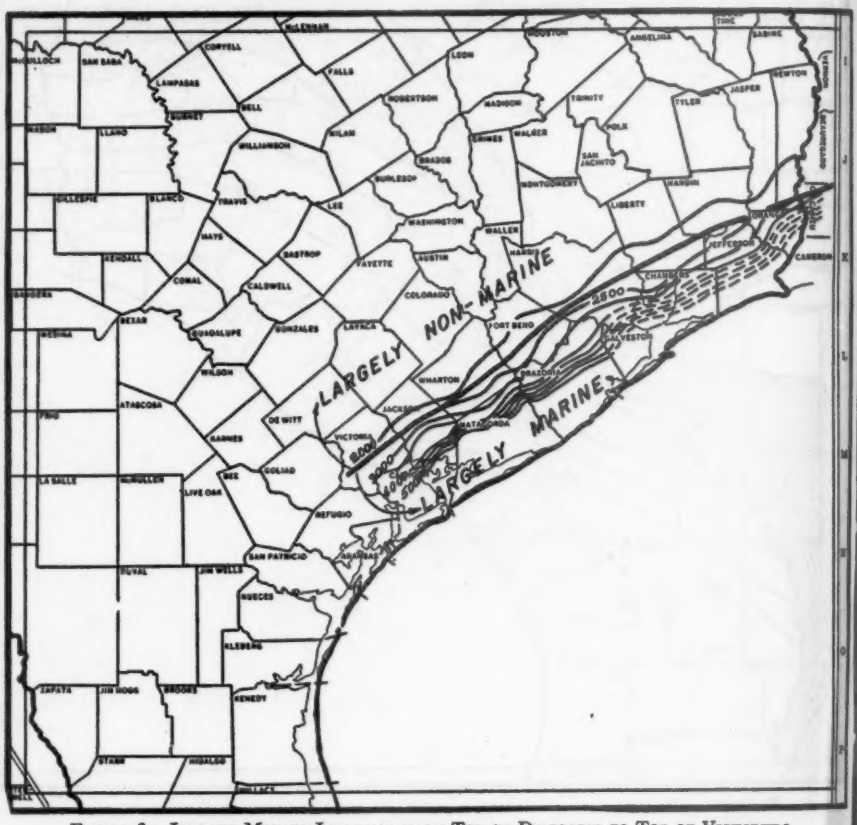
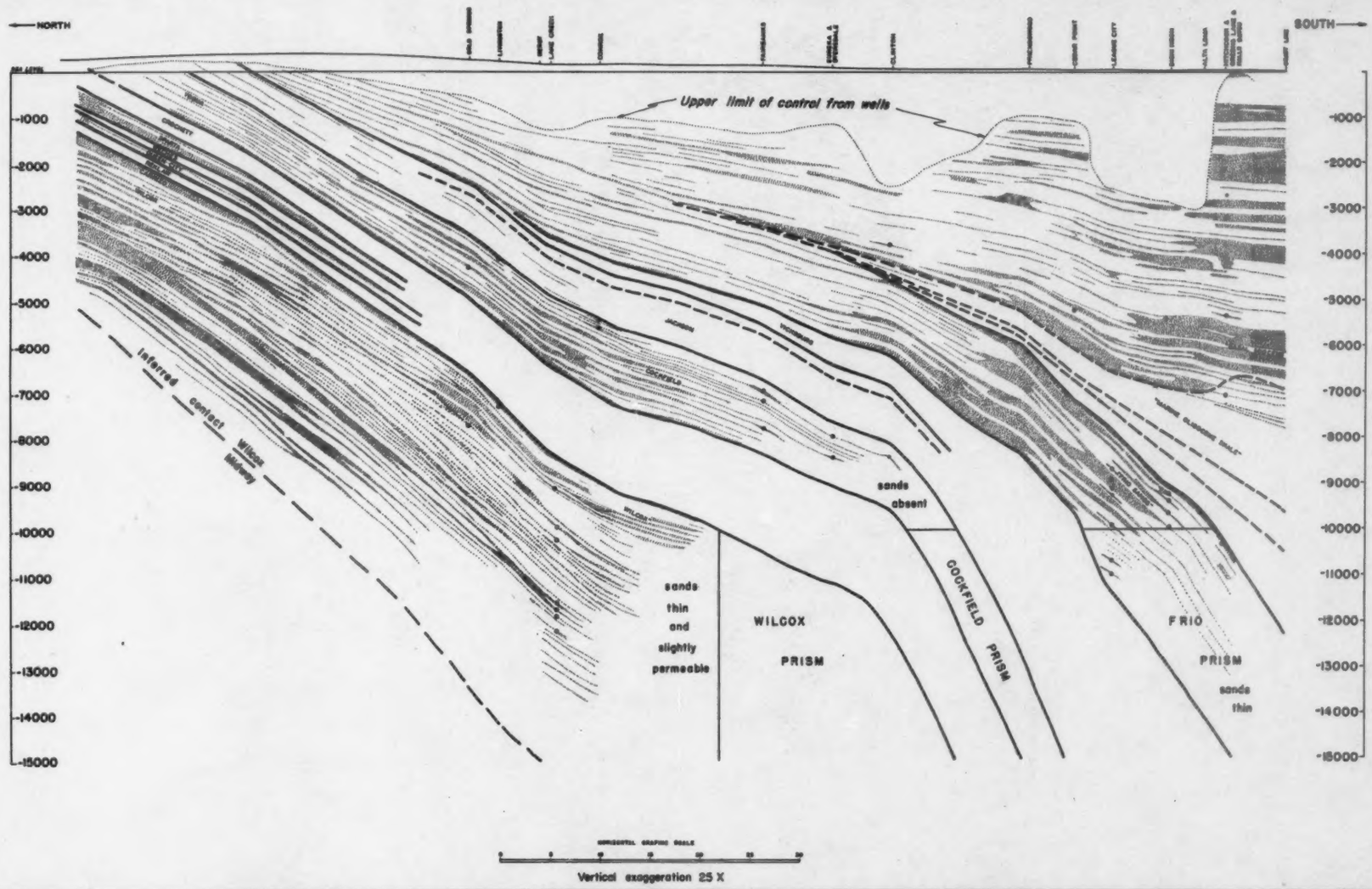


FIGURE 3.—ISOPACH MAP OF INTERVAL FROM TOP OF DISCORBIS TO TOP OF VICKSBURG

The significance of these flexures in causing a localized increase in sediments seaward from them is readily apparent from a comparison of Figures 2 and 3. Figure 2 shows the thickening of the Claiborne as a whole. Only the Reklaw, containing the oldest beds of this group, shows thickening as a late and mild part of the third flexure. Figure 3 shows the more accentuated thickening of beds affected throughout their deposition by the basin created by the fourth, or post-Vicksburg, flexure. The up-dip, pre-flexure thickness of both formations is about 2000 feet. Since the maps are on the same scale, the rate of thickening is about three times as much in the same distance down-dip in Figure 3 as in Figure 2.

These flexures differ significantly in their location relative to the shore line in their respective epochs. The first and second, in the Jurassic and early Comanche Cretaceous, respectively, occurred near the shore line, and the deposit contains much evaporite facies. The third flexure, predominant toward the end of Wilcox (Eocene), is on the average more than 100 miles seaward from the most inland known former coast of that sea. Its deposits seaward are mostly sandstone and required a supply of



DIAGRAMMATIC DIP SECTION THROUGH HOUSTON DISTRICT OF GULF COAST

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thousands of cubic miles of quartz grains, suggesting great rivers draining a large territory. The fourth, or post-Vicksburg, flexure is much closer to the innermost margin of its sea, but its deposits are also predominantly sand. The fifth flexure, like the third, is far out from its coast line. Distribution of sand members in its sediments suggests that present river systems may have occupied nearly the same locations during the deposition of its continental facies so that these sand beds spread out from present rivers rather than parallel to this present strike.

Factors in Calculating Volume of Sediments

In each formation deposited seaward subsequent to each flexure, thickening continues seaward in the deepest well which has been drilled, so it might appear justifiable to add for each formation still greater thickness down-dip than that observed in the deepest well.

There are two objections to such an indefinite extrapolation: (1) at certain points there are known maxima to the total sedimentary column, as explained in the accompanying paper by Nettleton. (2) the flexure zones are somewhat narrow, so it is difficult to visualize a strong relief inland behind them as would be required if a great prism of sediments extends far seaward from the flexure in the immediately succeeding geologic period. The absence of such a major source is confirmed by the near absence of any conglomerate members in the sandstones in front of the flexure, and also by the evidence that Wilcox and post-Vicksburg sandy beds locally become thinner and fewer at distances of 25–50 miles in front of the flexure.

These two considerations therefore require that the extrapolation of known thicknesses seaward be conservative. The calculation of thicknesses beyond those known has been made by using the average maximum observed thickness for each unit group of the sediments in the areas seaward from such observations, increasing this maximum only where the group was still rapidly thickening because the last observation was only a short distance seaward from the flexure, as, for example, the beds in front of the second flexure (Early Cretaceous). The sum of the average group units was then adjusted to be slightly below the geophysical maximum.

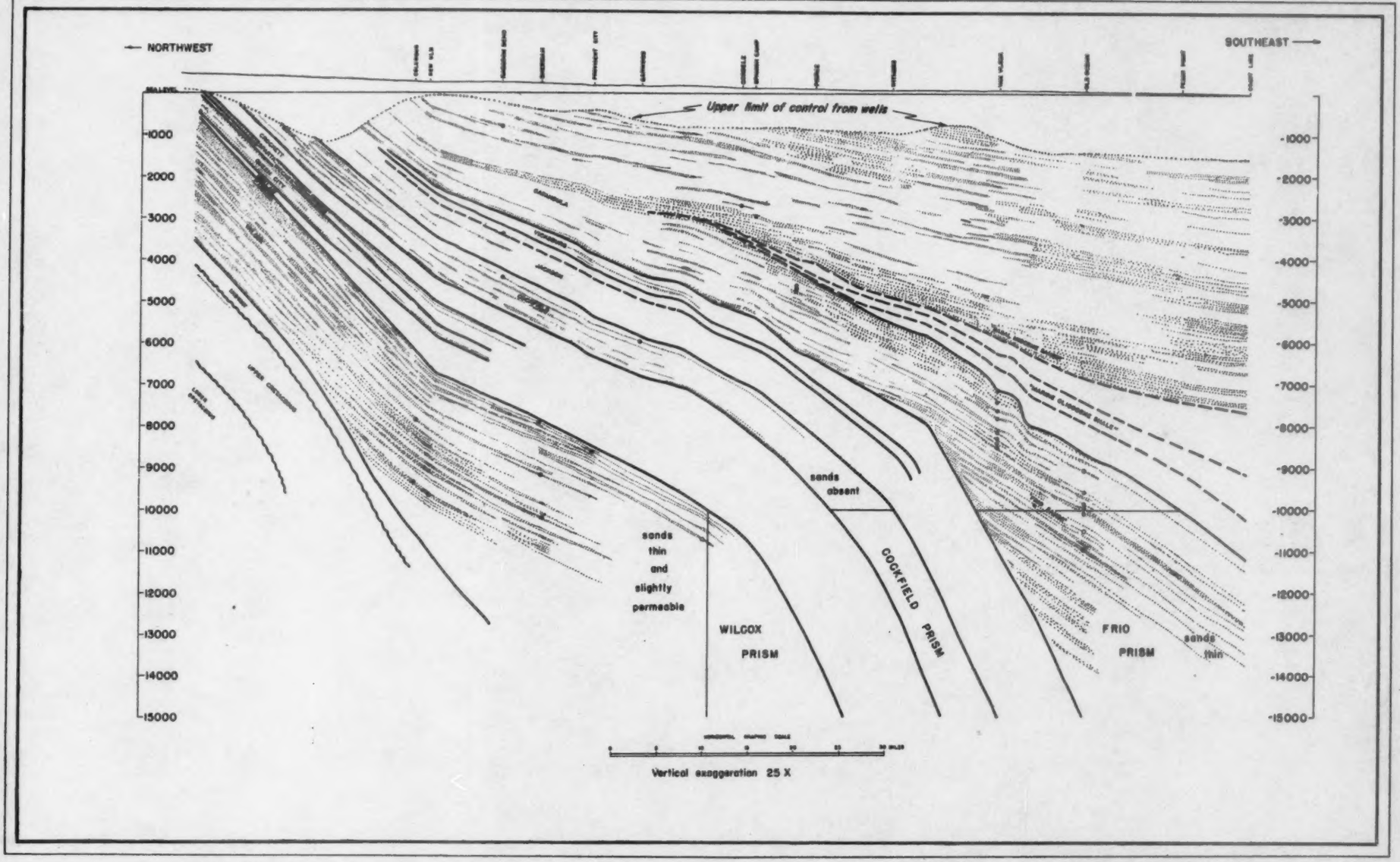
Formations under the Continental Shelf were calculated by using the same thickness as the adjacent ones on land for the area immediate to the coast, and by increasing the youngest groups, later Miocene and Plio-Pleistocene, toward the outer margin of the shelf, on the assumption that an additional flexure should be postulated half way seaward across the province. This assumption was made in the absence of geophysical, subsurface, and surface data except at the coast line, but seems warranted because these formations are known to thicken in South Louisiana where the land area extends farther down-dip than in Texas.

Summary of Calculation of Volumes

The calculations according to the geologic data and the methods of extrapolation which have been discussed in the preceding paragraphs have been made for each group of the Mesozoic and Cenozoic and are summarized in Table 1.

Table 1.—Volume of Mesozoic and Cenozoic Sediments in Western Gulf Coastal Plain

	Average Estimated Thickness at Coast Line (feet)	Volume of Sediments inland (cubic miles)	Volume of Sediments on continental shelf (cubic miles)
Triassic	Not known to be present		
Jurassic	7,000	111,000	40,000
Comanche Cretaceous	6,000	97,000	33,000
Gulf Cretaceous	2,000	34,000	11,000
Midwayan	1,500	25,000	8,000
Wilcox group	7,000	64,000	40,000
Claiborne group	5,000	43,000	27,000
Jacksonian	1,500	14,000	8,000
Vicksburgian	1,000	8,000	5,000
Hackberry-Frio	8,000	37,000	44,000
Later Miocene	4,000	14,000	33,000
Plio-Pleistocene	2,000	6,000	22,000
Total	45,000	453,000	271,000



DIAGRAMMATIC DIP SECTION ALONG LOWER COLORADO DISTRICT OF GULF COAST

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 63, PP. 1201-1220, 14 FIGS. DECEMBER 1952

SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF THE UNITED STATES AND MEXICO

PART V: VOLUMES OF MESOZOIC AND CENOZOIC SEDIMENTS IN MEXICAN GULF COASTAL PLAIN

BY EDUARDO J. GUZMÁN

ABSTRACT

Estimated total volume of sediments contained in certain Mesozoic and Cenozoic stratigraphic units in the Mexican Gulf Coastal Plain (excluding the Yucatán Peninsula) is of the order of 303,900 cubic miles. Breakdown of this volume by distribution and thickness of individual units is shown on an accompanying table and by isopachous maps.

During the Mesozoic era, most of the Mexican Gulf Coastal Plain apparently was a submerged shelf or foreland area along the eastern border of a great geosyncline that extended from Central America through Mexico, the United States, and Canada. Tremendous thicknesses of sediments accumulated in parts of this geosyncline, and relatively thin deposits formed on the shelf area except locally where large organic reefs grew. It is unknown whether the Mesozoic sediments thicken again to the east or continue thinning.

During Eocene time, several basins or foredeeps along the western margin of the present Coastal Plain received thick deposits of geosynclinal sediments (flysch and molasse), derived by erosion of the uplifted Mesozoic geosynclinal block. Lesser thicknesses of sediments were deposited east of these foredeeps. Whether the Eocene sediments thicken farther eastward under the Gulf of Mexico is at present unknown.

During Oligocene and later periods of the Cenozoic, it appears that the present Mexican Gulf Coastal Plain consisted of a number of embayments that extended off a great sedimentary basin. The deepest part of this basin was in the present Gulf of Mexico, similar to the conditions existing today.

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The writer is indebted to Manuel Rodríguez Aguilar and the management of Petróleos Mexicanos for permission to publish this paper.

Most of the basic data have been obtained from Petróleos Mexicanos files or from published work by Petróleos Mexicanos geologists including Alvarez (1949), Benavides (1949),

FIGURE 1.—INDEX MAP SHOWING AREA CONSIDERED FOR CALCULATIONS

Contreras (1950), Guzmán (1949; 1950), Ruiz (1950), Salas (1949), and Viniegra (1950). The excellent papers by Dr. Ralph W. Imlay (1943–1948) concerning the Mesozoic of North America have also been used extensively, particularly with regard to paleogeographic interpretation. Other pertinent published data to which the writer has referred are included in work by Burckhardt (1930), Cooke *et al.* (1943), Kane and Gierhardt (1935), Muir (1936), and Ver Wiebe (1949).

The writer is grateful to Santiago Hernández Sánchez who conscientiously assembled all the pertinent data, to Felipe Guerra Peña for the excellent drafting of maps and sections, and to Stewart H. Folk for many stimulating discussions of the problem and for reading and criticizing the manuscript.

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Introduction

The Mexican Gulf Coastal Plain is an irregular but continuous belt of land between the Sierra Madre and the Gulf of Mexico, extending southward and eastward from the Rio Grande through the Yucatán Peninsula (Figs. 1–13). In a strict physiographic sense, not all the area is coastal plain, for within it are several mountain ranges—the Sierra San Carlos, Sierra Tamaulipas, and others. The Sierra Madre front usually is considered the boundary of the coastal plain in Mexico because the topographic relief is relatively low and the geologic structure relatively simple in the region between the front ranges and the Gulf of Mexico as compared to the Sierra Madre. Furthermore, the stratigraphy and regional structure of all this so-called "Gulf Coastal Plain" in Mexico are closely related in many respects to the stratigraphy and structure of the Gulf Coastal Plain of the United States.

During Cenozoic time, most of the Mexican Gulf Coastal Plain was submerged in the form of embayments and small basins around the margins of the ancestral Gulf of Mexico, with land bordering it on the west and south; this of course was comparable to Cenozoic conditions in the Gulf Coastal Plain of the United States. But the situation during most of the Mesozoic era was quite different; in Upper Jurassic and a large part of Cretaceous time, the present Mexican Gulf Coastal Plain was a submerged platform or foreland shelf along the

Table 1.—Volumes and Areas of Stratigraphic Units

STRATIGRAPHIC UNITS	PRINCIPAL TYPES OF SEDIMENTS	AREA (Square miles)	VOLUMES (Cubic miles)
POST OLIGOCENE	MARINE AND NON MARINE SHALE, SAND, GRAVEL, CALICHE, LIGNITE, ASHES.	29,400	20,400
OLIGOCENE	MARINE AND NON MARINE SHALE, SAND, ASHES, LITTLE CONGLOMERATE AND REEF LIMESTONE.	51,150	48,700
EOCENE	MARINE AND NON MARINE SHALE, SAND, CALCAREOUS SAND AND CONGLOMERATE.	65,850	92,400
TOTAL CENOZOIC		67,200	161,500
UPPER CRETACEOUS	MARINE SHALE, MARL AND THIN BEDDED LIMESTONES; COAL IN NORTHERN MEXICO.	102,900	44,800
LOWER & MIDDLE CRETACEOUS	MARINE LIMESTONE (LOCALLY VERY THICK REEF DEPOSITS). ARKOSE AND OTHER CLASTICS IN NORTHERN MEXICO	120,200	65,800
UPPER JURASSIC	MARINE LIMESTONE AND SHALE; SANDSTONE AND CONGLOMERATE; RED BEDS, GYPSUM, SALT, TUFFS AND COAL.	84,900	31,800
TOTAL CRETACEOUS AND UPPER JURASSIC		122,800	142,400
TOTAL		122,800	303,900

Figure 1.—Index Map Showing Area Considered for Calculations

FIGURE 2.—UPPER JURASSIC LOCALITIES

FIGURE 2.—UPPER JURASSIC LOCALITIES

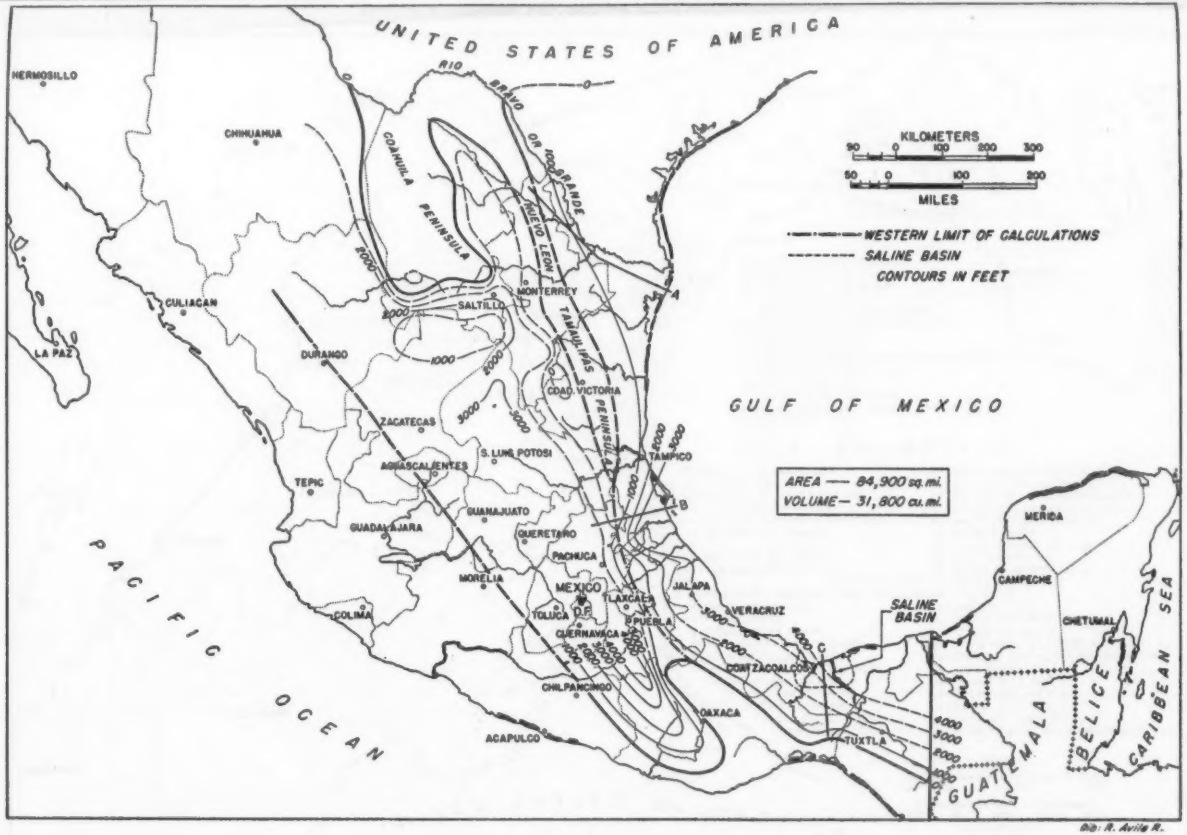

FIGURE 3.—UPPER JURASSIC ISOPACHS

FIGURE 4.—LOWER AND MIDDLE CRETACEOUS LOCALITIES

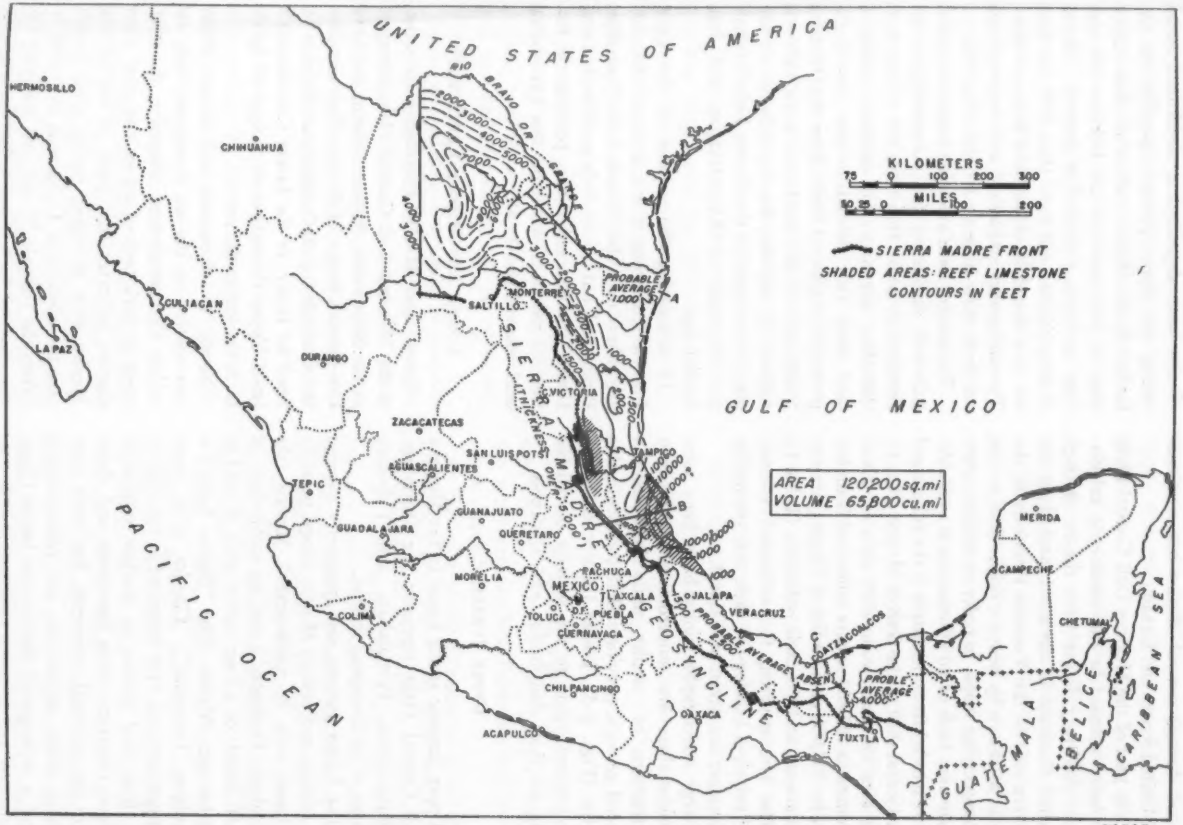

FIGURE 5.—LOWER AND MIDDLE CRETACEOUS ISOPACHS

eastern side of the great geosyncline that extended through central Mexico into west-central United States and Canada.

Only part of the Mexican Gulf Coastal Plain has been included in the volumetric calculations. Arbitrary limits were drawn through western Coahuila in the north and along the western side of the Yucatán Peninsula in the south, as shown by heavy straight lines on the accompanying maps, in order to exclude areas where very little or no information is available. Also excluded from this paper is the submerged continental shelf of the Gulf of Mexico (Fig. 1). The area for which volumetric data are given amounts to 122,800 square miles and is underlain by 303,900 cubic miles of Upper Jurassic, Cretaceous, and Cenozoic sediments (Table 1).

The area covered, the estimated volume, and principal lithology of each unit treated by this paper are given in Table 1.

Large stratigraphic units have been used because there are numerous uncertainties in correlations of smaller units between the several geologic provinces that constitute this region (Figs. 2–5). Lower Jurassic sediments are omitted owing to the scarcity of reliable data on their distribution and thickness.

Upper Jurassic

Upper Jurassic strata found in the Mexican Gulf Coastal Plain represent the Oxfordian, Kimmeridgian, Portlandian, and Tithonian Stages of the European section.

The Upper Jurassic sea apparently covered all eastern and central Mexico except possibly a broad area in north-central Mexico (the "Coahuila Peninsula") and an archipelago of small islands or a long narrow strip of land in northeastern Mexico (the "Nuevo León-Tamaulipas Peninsula"). Clastics with some gypsum and coal were deposited in the vicinity of these land masses or shallow submarine ridges; elsewhere black limestones and shales were the principal sediments. Red beds comprising shales, sandstones, and conglomerates have a wide-spread distribution below Upper Oxfordian and in some localities overlie Lias beds; they have been referred to the Lower Oxfordian. Oölitic and coralline limestones occur locally in Upper Jurassic strata.

In the Isthmus of Tehuantepec, thick beds of salt were deposited in semiclosed basins during the Upper Jurassic, possibly the Oxfordian Stage. (Recent subsurface data suggest that at least some of the Isthmus salt beds may be Tertiary instead of Jurassic.) Masses of recrystallized salt more than 8500 feet thick are now found in domes and long anticlines. The salt grades southward and westward into red beds with little or no salt (Fig. 14).

The meager data available suggest a general gulfward thickening for Kimmeridgian and Portlandian beds. However, the sediments of Oxfordian age may thin eastward toward a land mass that existed in the area of the present Gulf Coastal Plain. After the Oxfordian Stage, most of this land mass apparently was covered by the sea, leaving only its western margin emergent as the Nuevo León-Tamaulipas Peninsula of Kimmeridgian and Portlandian age.

In calculating the volume of the Upper Jurassic sediments, it was assumed that they are absent over the "Nuevo León-Tamaulipas Peninsula", but it is entirely possible that some Upper Jurassic sediments, particularly continental red beds, occur on this hypothetical land mass (Figs. 2, 3).

Lower and Middle Cretaceous

Lower and Middle Cretaceous formations of the Mexican Gulf Coastal Plain correspond to the Neocomian, Aptian, Albian, and Lower Cenomanian Stages of Europe. They constitute the Coahuilan and Comanchean Series as defined by Imlay, or the Lower Cretaceous and basal Upper Cretaceous as recognized by the U. S. Geological Survey.

Nearly all of eastern and central Mexico was covered by the sea throughout early and middle Cretaceous time. However, the occurrence of thick beds of arkose and other coarse clastics indicates that parts of north-central Mexico were emergent during some periods, and the absence of Cretaceous sediments between the Jurassic (?) salt and overlying Tertiary beds in the Isthmus Saline Basin suggests that the latter area might not have been covered by the Cretaceous sea.

Distribution of facies and sediment thick-

nesses indicate that most of the present Mexican Gulf Coastal Plain was a submerged foreland shelf or platform along the eastern side of the Cretaceous geosyncline that extended westward and northward from Central America through Mexico, west-central United States, and Canada.

Lower and Middle Cretaceous rocks of the Mexican Gulf Coastal Plain are for the most part marine and consist largely of dense limestones, with interbeds of shale and marl.

Reef limestones, composed of rudistid and other organic remains, occur at some localities. One such reef, which has a typically biohermal structure, is more than 8500 feet thick and forms an arcuate subsurface ridge more than 80 miles long; the crestal portion of the reef is the reservoir of the famous Golden Lane fields which have yielded over a billion barrels of oil and still are producing. Other fields, including Poza Rica from which the ultimate recovery probably will be even greater than that from all the Golden Lane fields, produce from limestones that may be fore-reef beds of the Golden Lane bioherm.

Thick sections of coarse clastic sediments supposedly of early and middle Cretaceous age are found in north-central and western Mexico, near the western margin of the extensive Cretaceous sea.

Lower and Middle Cretaceous formations are less than 2000 feet thick throughout most of the Coastal Plain area except for locally thick reef limestone masses, but farther westward they generally thicken considerably and are more than 15,000 feet in north-central Mexico.

The limited information now available indicates that the regional thinning continues eastward under the Gulf of Mexico (Figs. 4, 5).

Upper Cretaceous

Upper Cretaceous sediments of the Mexican Gulf Coastal Plain represent the Upper Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maestrichtian Stages of Europe. Uppermost Cretaceous sediments of Danian age have not been definitely identified.

The strata consist of a regressive series of thin-bedded limestones, shales, and marls, with occasional thin silty and sandy layers. Both local and regional lateral variation of lithologic characteristics is common. Some Upper Cretaceous coal occurs in northern Mexico.

The Upper Cretaceous sea apparently covered most or all of eastern Mexico and part of central Mexico. Upper Cretaceous sediments are absent below Cenozoic formations in a few places in the Gulf Coastal Plain, notably on the crest of the Golden Lane bioherm near Tampico, and in the Isthmus Saline Basin in the vicinity of Coatzacoalcos; these areas possibly were emergent during the late Cretaceous. They may also be absent in the Sierra San Andrés Tuxtla, a volcanic mountain range near the coast, southeast of Veracruz. Some geologists consider this Sierra to be a pre-Mesozoic massif, but for this paper it is considered as emergent only during Cenozoic time.

Sediments of this age generally thicken gulfward, although they are locally very thick in several places along the western margin of the present Coastal Plain (Figs. 6, 7).

Eocene

The Eocene as here used includes the Midway, Wilcox, Claiborne, and Jackson Stages, and thus represents both Paleocene and Eocene of other authors.

At the close of the Cretaceous or possibly later during the Eocene, the sediments in the Mexican Mesozoic geosyncline were folded and uplifted, forming the Sierra Madre. The numerous large overturned folds and thrust faults in the front ranges of the Sierra Madre show that the present Coastal Plain region acted as a buttress against this deformation. The Sierra Madre region remained emergent throughout the Cenozoic era.

During Eocene time there were several troughs or foredeeps parallel to the Sierra Madre front and along the western margin of the present Gulf Coastal Plain in central and southern Mexico. Great thicknesses of sediments of the flysch and molasse types accumulated in these troughs. Elsewhere along the western margin of the Coastal Plain, continental and near-shore marine clastics were deposited; these grade eastward into marine sediments.

In northeastern Mexico, the Eocene sediments consist of deltaic deposits and appar-

UNITED STATES OF AMERICA
RIO BRAVO OR GRANDE
HERMOSILLO
CHIHUAHUA
CULIACAN
LA PAZ
DURANGO
SALTILLO
MONTERREY
C. VICTORIA
ZACATECAS
SAN LUIS POTSI
AGUASCALIENTES
TEPIC
GUANAJUATO
QUERETARO
GUADALAJARA
MORELIA
COLIMA
PACHUCA
MEXICO
D.F.
TOLUCA
CUERNAVACA
PUEBLA
TLAXCALA
JALAPA
VERACRUZ
TAMPICO
GULF OF MEXICO
PACIFIC OCEAN
CHILPANCINGO
ACAPULCO
OAXACA
COATZACOALCOS
TUXTLA
MERIDA
CAMPECHE
CHETUMAL
GUATEMALA
BELICE
CARIBBEAN SEA
KILOMETERS
MILES
1 - LOMAS; BETWEEN NAVAJA & CASA ROJA
2 - SABINAS BASIN, BETWEEN BARROTERAN & JUAREZ
3 - SAN AMBROSIO WELL Nº 1
4 - ESCALERA ANTICLINE, NEAR NUEVO LAREDO
5 - LAS TORTILLAS VILLAGE
6 - AREA NORTH OF ARENAL, GRAL. TREVIÑO, STA. ERTRUDIS, ROMA, OCHOA & MIER
7 - SIERRA DE PAPAGAYOS
8 - MIER, RAMONES & CAMARGO AREA
9 - AREA SOUTH OF ARENAL, CHINA, RAMONES, JABALI, RIO BRAVO, ETC.
10 - MENDEZ, VAQUERIA AREA
11 - BURGOS & CRUILLAS AREAS
12 - SIERRA DE CRUILLAS
13 - " SAN CARLOS
14 - AREA BETWEEN JIMENEZ & CRUILLAS
15 - " SOTO LA MARINA & ABASOLO
16 - JAUMAVE
17 - VICTORIA & JAUMAVE VALLEYS
18 - HUIZACHAL
19 - MONTECRISTO
20 - ARROYO PRADA-LLERA
21 - LA BORREGA CANYON
22 - ARROYO ESPADEÑO
23 - SAN JOSÉ DE LAS RUSIAS AREA
24 - CAPELLANIA, TINAJITAS & GRULLO WELLS
25 - SAN RAFAEL WELL Nº 1
26 - SIERRA DE CHAMAL
27 - CANOAS AREA
28 - SANTA CLARA AREA
29 - 30 - PANUCO, EBANO, CACALILAO & CHOCOY WELLS
31 - WEST OF HUICHES
32 - SIERRA DEL ABRA
33 - SOUTH OF TAMPAON RIVER
34 - CERRO DEL GUAJOLOTE
35 - XILITLA
36 - SAN PEDRO ANTICLINE
37 - TAMAZUNCHALE
38 - BUSTOS WELL Nº 1
39 - RANCHO NUEVO WELLS
40 - TANCEME WELL Nº 1
41 - COMALES & AGUADA WELLS
42 - CERRO DE ORO, CINCUENTA & WELLS EAST OF GOLDEN LANE
43 - SANTA MARIA ICATEPEC Nº 1
44 - TLACOLULA WELLS
45 - TENEXCO "
46 - ARROYO TUTITLAN
47 - AMATITLAN, POSTECTITLA & STA. CRUZ DE JUAREZ AREA
48 - ASUNCION WELLS
49 - AGUA MACIDA WELLS
50 - METLALTOYUCA WELL Nº 1
51 - TIHUATLAN AREA
52 - POZA RICA-MECATEPEC WELLS
53 - ARROYO GRANDE WELL Nº 1
54 - PALMA SOLA WELL Nº 10
55 - HUEHUETLA
56 - CHUMATLAN
57 - COETZALAH
58 - EAST OF ALMANZA
59 - TLAPACOYAN
60 - AYOTOXCO & GACHUPINATE WELLS
61 - TEZIUTLAN
62 - ARROYO QUILATE
63 - COMAL ANTICLINE
64 - BETWEEN PLAYAS & NANCHITAL RIVERS
65 - CERRO PELON ANTICLINE
66 - SOUTH-WEST OF TEPACTAN
67 - WEST OF OCOZOCUAUTLA
68 - LA DANTA & AGUA BLANCA ARROYOS
69 - PASO MONO & DEL GUAYAL HILLS

FIGURE 6.—UPPER CRETACEOUS LOCALITIES

FIGURE 6.—UPPER CRETACEOUS LOCALITIES

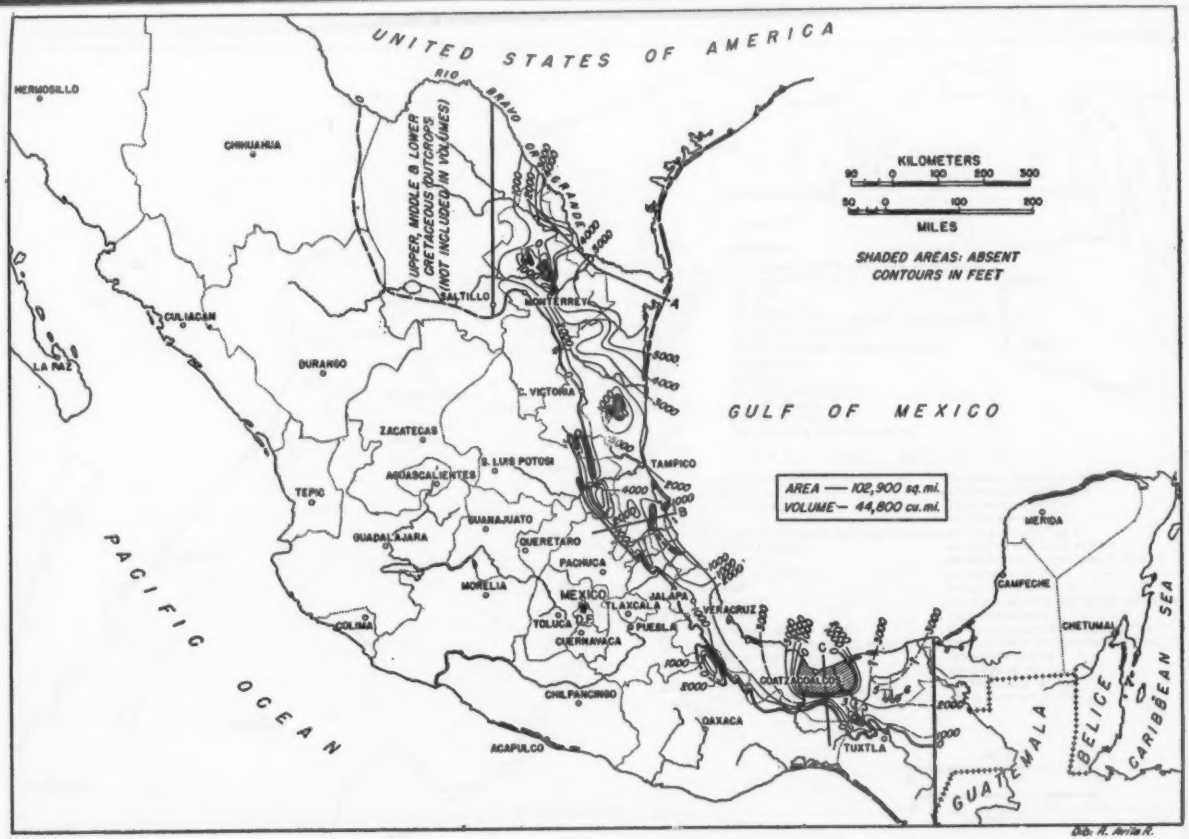

FIGURE 7.—UPPER CRETACEOUS ISOPACHS

FIGURE 8.—EOCENE LOCALITIES (INCLUDING PALEOCENE)

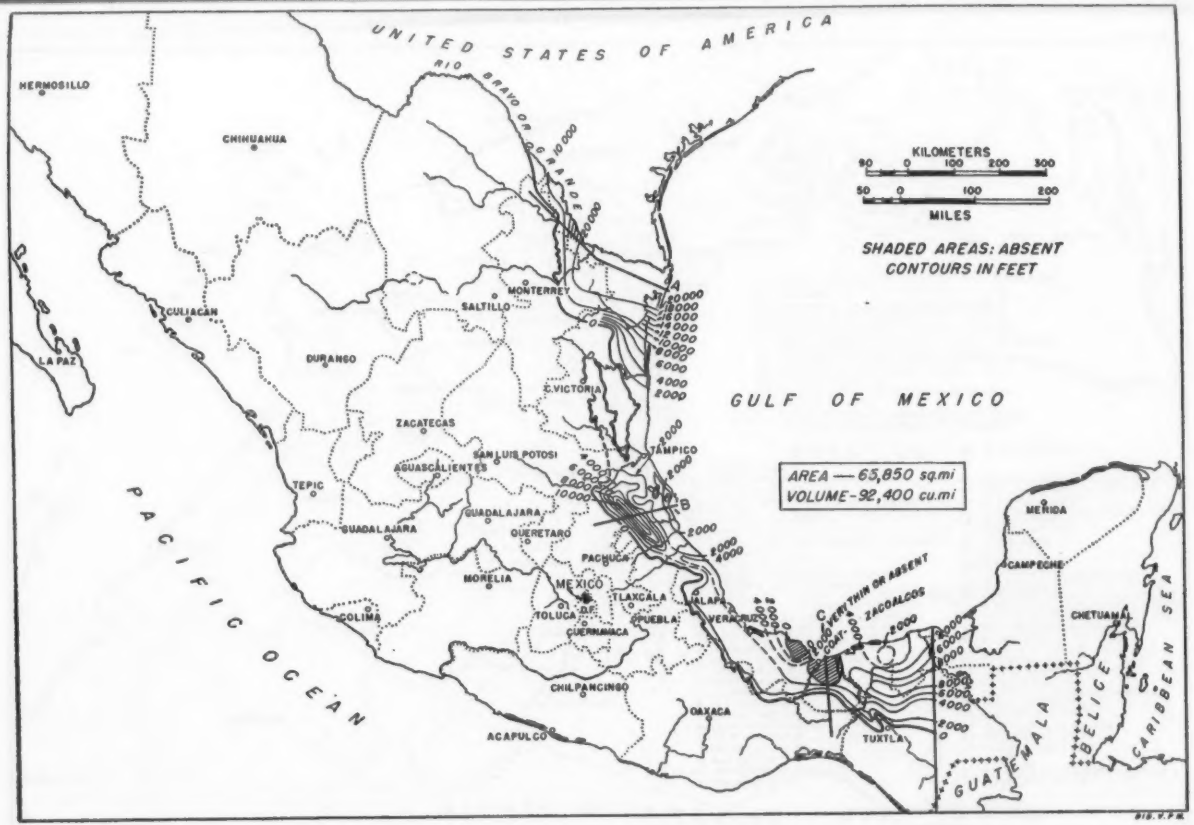

FIGURE 9.—EOCENE ISOPACHS (INCLUDING PALEOCENE)

UNITED STATES OF AMERICA
RIO BRAVO OR GRANDE
HERMOSILLO
CHIHUAHUA
CULIACAN
LA PAZ
DURANGO
MONTERREY
SALTILLO
C. VICTORIA
ZACATECAS
SAN LUIS POTOSI
AGUASCALIENTES
TEPIC
GUANAJUATO
QUERETARO
GUADALAJARA
PACHUCA
MEXICO
MORELIA
TOLUCA
PUEBLA
TLAXCALA
JALAPA
VERACRUZ
COLIMA
CUERNAVACA
CHILPANCINGO
ACAPULCO
OAXACA
TUXTLA
TAMPICO
COATZACOALCOS
MERIDA
CAMPECHE
CHETUMAL
GUATEMALA
BELICE
CARIBBEAN SEA
PACIFIC OCEAN
GULF OF MEXICO
KILOMETERS
MILES
1 - CAMARGO WELLS
2 - VALADECES WELL Nº 1
3 - MISION WELLS
4 - RIO BRAVO WELLS
5 - REYNOSA WELLS
6 - FRANCISCO CANO WELLS
7 - TREVIÑO WELLS
8 - 18 DE MARZO WELLS
9 - RIO BRAVO WELL Nº 10
10 - MONTERREY WELLS
11 - ZACATE WELLS
12 - EAST FLANK OF EL ARENAL
13 - MENDEZ (CONCHOS RIVER)
14 - CRUILLAS & MENDEZ AREAS
15 - EAST-WEST SECTION
16 - AREA BETWEEN JIMENEZ & CRUILLAS
17 - " " JIMENEZ & ABASOLO
18 - " " SOTO LA MARINA & ABASOLO
19 - GRULLO & TINAJITAS WELLS
20 - SAN JOSE DE LAS RUSIAS WELLS
21 - SAN RAFAEL WELL Nº 1
22 - BUSTOS WELL Nº 1
23 - LA LAJA, GRANADILLA & RCHO. NUEVO WELLS
24 - AGUADA WELLS
25 - TANCEME WELL Nº 1
26 - PECERO
27 - VICINITY OF AGUADA & CHILA CORTAZA
28 - PITAHAYA WELLS
29 - CERRO DE ORO, CINCUENTA & WELLS E. OF GOLDEN LANE
30 - MORALILLO WELLS
31 - GOLDEN LANE & TIERRA AMARILLA WELLS
32 - ASUNCION WELL Nº 3
33 - AGUA NACIDA WELLS
34 - AREA SOUTH OF TUXPAN
35 - MIAHUAPAN WELLS
36 - ACONTITLA WELL Nº 4
37 - MECATEPEC & POZA RICA WELLS
38 - ESCOLIN WELL Nº 6
39 - ARROYO GRANDE WELL Nº 1
40 - SAN MARCOS WELL Nº 1
41 - ARROYO TAJALATE
42 - PLAYA VICENTE
43 - RODRIGUEZ CLARA WELL Nº 1
44 - ARROYO TIZALPOTE (BETWEEN SAN ANDRES TUXTLA & RODRIGUEZ CLARA)
45 - SABANETAS-TIERRA NUEVA AREA
46 - CUITLAXOYO WELL Nº 1
47 - SAN JUAN EVANGELISTA AREA
48 - ACHOTAL AREA
49 - SAYULA
50 - TEXISTEPEC
51 - OJAPA
52 - POTRERILLOS FIELD
53 - TANCANICHAPA-PERA BLANCA AREA
54 - COACHAPA RIVER
55 - SAN CRISTOBAL WELL Nº 1
56 - NORTH OF ARROYO PEDREGAL ON THE ROAD FROM TECUANAPA – LA INDICACION AND OUTCROPS IN THE UZPANAPA RIVER
57 - CASCAJAL DOME
58 - ISTHMUS WELLS AND SEISMOLOGICAL DATA
59 - PLAYAS ANTICLINE
60 - UPPER PART OF PEDREGAL RIVER
61 - JUNCTION OF GRIJALVA AND LA VENTA RIVERS
62 - AREA BETWEEN MEZCALAPA, LA VENTA & GRIJALVA RIVERS
63 - MACUSPANA RIVER
64 - AGUA BLANCA SYNCLINE
65 - CHACAMAX RIVER SOUTH OF PALENQUE
66 - GUERRERO WELL Nº 1
67 - JALPA WELL Nº 1

FIGURE 10.—OLIGOCENE LOCALITIES

FIGURE 11.—OLIGOCENE ISOPACHS

FIGURE 12.—POST-OLIGOCENE LOCALITIES

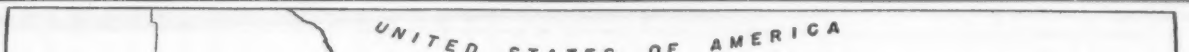

FIGURE 12.—POST-OLIGOCENE LOCALITIES

FIGURE 13.—POST-OLIGOCENE ISOPACHS

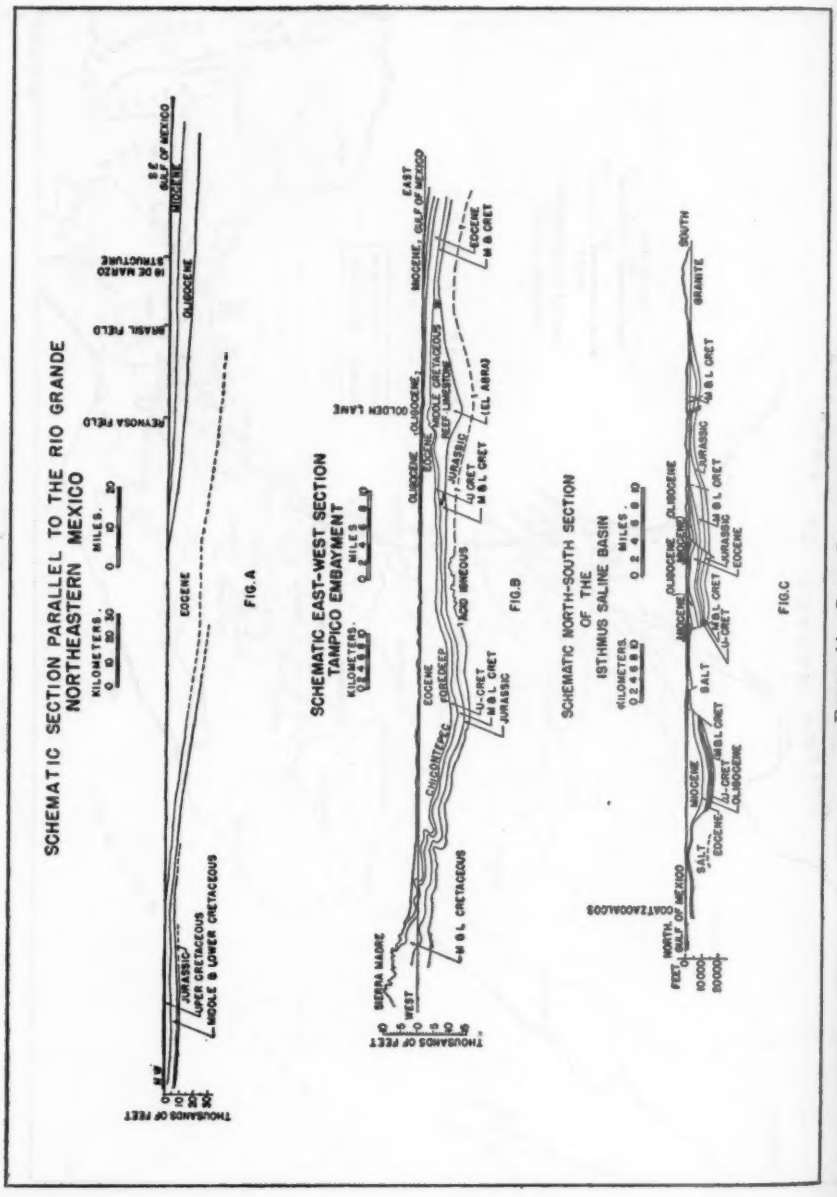

FIGURE 14.—CROSS SECTIONS

FIGURE 14.—CROSS SECTIONS

ently continue thickening eastward from the outcrop belt to at least as far as the coastline, where they probably reach a thickness of more than 20,000 feet.

Eocene strata are abnormally thin or absent in some areas near the present coast line of the Gulf of Mexico, as for example in the Sierra Tamaulipas, over the Golden Lane bioherm in the Tampico region, in the Sierra San Andrés Tuxtla, and in the Isthmian Saline Basin in the vicinity of Coatzacoalcos (Figs. 8, 9).

OLIGOCENE

The Oligocene formations of Mexico are approximately equivalent to the Vicksburg, Frio, and Anahuac of Texas.

During the Oligocene, the sea continued its eastward regression, interrupted by at least one westward transgressive movement in early Oligocene time.

Oligocene sediments are present everywhere east and north of the outcrop belt, except possibly in the Sierra San Andrés Tuxtla southeast of Veracruz and over some domes in the Isthmus Saline Basin.

Depositional conditions were similar to those existing today. Along the outcrop, belt sediments consist of near-shore clastics that grade eastward into marine shales. In general the Oligocene sediments thicken gulfward at least as far east as the present coast line. Coral-reef limestones of Oligocene age exist in the Tampico region and in the Isthmus of Tehuantepec (Figs. 10, 11).

POST-OLIGOCENE

Under this heading are grouped Miocene, Pliocene, Pleistocene, and Recent sediments.

Marine sediments of these periods were deposited under conditions almost identical with those existing in the Gulf of Mexico today. The coast line moved progressively eastward until it attained its present position. An important transgression occurred in the southern Gulf Coast during Lower Miocene (Upper Concepción formation) when the sea again covered most of the present Coastal Plain along the northern part of the Isthmus of Tehuantepec.

Miocene and Pliocene sediments are believed to be present everywhere east and north of their outcrop belts except possibly in the Sierra San Andrés Tuxtla. These sediments consist of sands and shales that thicken and grade gulfward into deeper-water facies. Volcanic tuffs and ashes are abundant in some formations. Lignitic beds are present in Upper Miocene strata of the Isthmus; in the Yucatán Peninsula, Miocene and Pliocene strata are predominantly limestones.

Pleistocene and recent gravel and caliche cover extensive areas in northeastern Mexico, and continental sediments of various types are found locally throughout the Coastal Plain region (Figs. 12, 13).

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PETROLEOS MEXICANOS, MEXICO D. F., MEXICO

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SEDIMENTARY VOLUMES IN GULF COASTAL PLAIN OF THE UNITED STATES AND MEXICO

PART VI: GEOPHYSICAL ASPECTS

BY L. L. NETTLETON

ABSTRACT

The Gulf Coast of Texas and Louisiana has been geophysically explored more intensively than any comparably large area in the world, but the indications of the depth and configuration of the basin derivable from this work are limited. Gravity data are of very little use. Magnetic data give general indications of the basement depth. Normal reflection-seismograph data give detail between and beyond bore holes but rarely reach to greater depths than the deepest drilling. Special reflection surveys over a few salt domes give indications of the depth to the base of the salt column.

The principal conclusions reached by consideration of all the available geophysical results are: (1) The regional dip toward the Gulf of Mexico extends to the coast line without any indications of a synclinal axis at or immediately beyond the coast, and (2) The thickness of sediments at the coast line is about 40,000 feet, and (3) Pre-salt sediments are thin, absent, or metamorphosed.

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INTRODUCTION

Extensive commercial geophysical exploration has been carried out in the Gulf Coastal Plain, particularly in Louisiana and Texas. In fact, this region has been more intensively explored by all geophysical methods than any comparable large area in the world. Also, the area has now been extensively and deeply drilled for oil. The geophysical data are of limited use in adding information between, beyond, and below direct observations from deep wells and thereby contributing to our understanding of the general configuration of the Gulf Coast embayment and the volume of sediments which it contains.

The information that can be derived from these data is less definite and extensive than might be expected. Commercial geophysical exploration in the Gulf Coast is carried out primarily to find and detail local structures, particularly salt domes and associated sedimentary disturbances, and is not designed to be applied specifically to regional geological problems. Gravity and magnetic surveys can yield limited regional indications, and the latter can be used to suggest the order of magnitude of the total thickness of sediments.

The reflection-seismograph work does not give definite information much deeper than the deepest drilling, but does give much more continuous detail.

Acknowledgments

The data used for this analysis have been supplied by several oil companies with extensive geophysical operations in the Gulf Coast of Texas and Louisiana. Three companies have each assembled one of the combination reflection-seismograph and deep-well profiles discussed later. They and others have supplied the gravity and magnetic data. Special acknowledgment is made to Mr. Paul Weaver and the Gulf Oil Corporation for much general and specific information incorporated in this report.

Utility of Commercial Geophysical Data

All the commercial geophysical methods have been applied, almost from the beginning of their use, to exploration in the salt-dome belt of the Texas and Louisiana Gulf Coast. This has resulted in coverage of this area by gravity surveys with close control, by magnetic surveys with relatively wide control, by refraction-seismograph surveys which are mostly local and related to specific exploration problems, and by a tremendous volume of reflection-seismograph exploration. These reflection surveys have covered the area in great detail but are not available for assembly into a uniform system of mapping because of their commercial and competitive nature and also because of the wide differences in the date and manner of conducting the field work and of mapping the results.

Gravity Surveys

Regional gravity maps of the Gulf Coast show prominent positive and negative features with trends more or less parallel to the coast line. These large features have been known for many years, and there has been much speculation as to their possible significance as indications of regional structure. The simplest and most prominent of these is an elongated minimum, with a nearly east-west trend, which crosses southern Louisiana from the Sabine River at Orange, Texas, to the Mississippi River about 10 miles south of Baton Rouge, Louisiana. This and other prominent gravity features are shown by a recently published regional gravity map at 10-mg. contour interval (Nettleton, 1949). A gravity profile from this map is included with one of the geologic cross sections of this report (Fig. 3).

The south Louisiana gravity minimum has a relief of the order of 30 mg. and a width of the order of 50 miles from the axis of the minimum to adjacent regional positive axes. Three possible causes of this minimum are: (1) density contrasts within the sediments; (2) density contrasts between the sediments and the basement; and (3) density contrasts within the basement rocks.

For a density difference of, say, 0.25 gm/cm^3, the relief of 30 mg. requires a thickness of some 10,000 feet. This means that the geologic explanation must account for an area of lighter rocks, roughly coextensive with the area of the gravity minimum and with a maximum thickness of the order of 10,000 feet at the minimal axis. The cross section (Fig. 3) shows a monoclinal south dip entirely across the minimum. If the gravity feature is to be explained by effects within the volume of sediments explored by the drill, we must resort to some sort of facies change, or systematic variation in character of the rocks, to provide the required density contrast. It seems hardly possible that an area as large as this minimum (some 60 miles wide by 300 miles long) could have received systematically lighter sediments of the required thickness.

A negative density contrast of the sediments with respect to the underlying basement rocks is to be expected. The minimum might then be due to a downwarping of the basement floor and a corresponding thickening of the lighter sedimentary rocks. Again, we may guess that a density contrast of the order of 0.25 gm/cm^3 would be reasonable and the syncline would have to be some 10,000 feet deep, with its axis approximately under the gravity axis. This synclinal interpretation was proposed by Barton (Barton *et al.*, 1933) on the basis of torsion-balance surveys and has been suggested again recently by Carsey (1950, p. 363). This is possible but not very probable. Figure 3

indicates a monoclinal coastward dip entirely across the minimum, with the dip increasing with depth. This condition is established to depths of some 10,000 to 12,000 feet and the postulated syncline would have to begin below the depths reached by the drill and reflection seismograph records. The synclinal interpretation is not supported by the magnetic data. Furthermore, none of the other large gravity features of the Gulf Coast correspond with any known regional structural trends, as is indicated by the comparison of the regional gravity map with this portion of the tectonic map of the United States (Nettleton, 1949, p. 278–279). Therefore, we are inclined to believe that, in the Gulf Coastal embayment, the gravity features do not indicate the gross configuration of the basement surface.

Density contrasts within the basement rocks remain as the most reasonable explanation of the large gravity minimum across south Louisiana. As pointed out later, the basement depth in this area is indicated to be of the order of 35,000 feet. The width of the gravity anomaly is great enough for it to be accounted for by density contrasts well below this depth. It seems probable, therefore, that the primary cause of this and other large gravity features is density contrasts deep within the basement rocks.

In the analysis of detailed gravity surveys of individual domes, forms may be assumed for the salt, their gravity effects can be calculated and compared with those observed, and the process repeated until forms are found which will accurately account for the measured gravity effects. The calculation of such forms involves assuming depths from which the salt rises and therefore the thickness of the post-salt sediments. This process is inaccurate in principle and is strongly dependent upon assumptions of density contrasts at depths far beyond any reached by the drill. An analysis of this type, therefore, cannot be considered as indicating more than the order of magnitude of the vertical length of the salt columns. Because of these very serious uncertainties, the results of such calculations have not been included in this report.

The net result of the consideration of gravity data is that they give practically no reliable indication of the configuration or depth of the sedimentary basin. The primary reason for this failure is the fundamental ambiguity in assigning specific sources to gravity disturbances, because, as pointed out, for instance, by Skeels (1947), a given gravity pattern can be accounted for by a variety of mass distributions. This ambiguity makes it uncertain whether a given gravity disturbance is caused by the configuration of a sedimentary basin or by density contrasts entirely below the sedimentary section, provided only that it is broad enough to have a very deep origin.

Magnetic Surveys

Magnetic fields are subject to the same mathematical ambiguity of the depth and configuration of bodies causing them as are gravity fields, because both are "potential" fields. However, geologically, magnetic surveys are less ambiguous than gravity surveys because the igneous and metamorphic rocks are many times more magnetic than the sediments, so that, in nearly all cases, the source of the magnetic disturbances begins at the surface of the igneous or metamorphic basement. Under certain assumptions as to the general form of the magnetized bodies, calculations can be made of the depth to the upper limits of the magnetic contrasts which are responsible for the anomalies observed. Such calculations give a rough measure of the probable maximum depth to the surface of the igneous or metamorphic rocks and therefore of the thickness of the sedimentary section.

Figure 1 shows the results of a number of such calculations, indicated by figures in squares which give depths, in thousands of feet, calculated from regional magnetic surveys. In a general way, these figures show increasing depths toward the coast with values of around 35,000 feet along and near the coast. Values in the range from 9000 to 19,000 feet in a small group in eastern Texas are much too shallow to be fitted into other indications, and it seems necessary to discount them as unreliable, probably because of superficial disturbances, as the control on which they are based is not as close as would be desired. Probably the most reliable single value is the depth of 35,000 feet just offshore at the southeast corner of Texas.

This is based on an air-borne magnetic survey carried out recently by the United States Geological Survey (Balsley, 1949). The other problem because the surveys are usually made in relatively small areas for special subsurface investigations and, for the most part, are

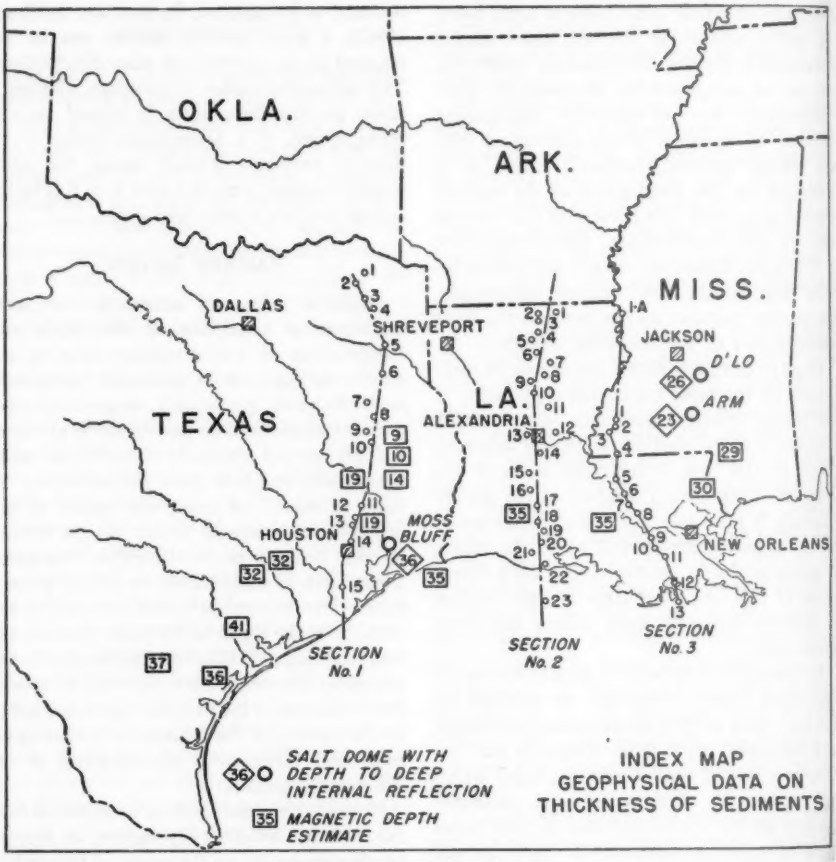

FIGURE 1.—INDEX MAP

Showing lines of cross sections, magnetic basement depth estimates, and salt depths from internal reflections in salt domes. Depths in thousands of feet.

calculations are all based on ground surveys.

Any single one of the magnetic depth estimates cannot be considered reliable to better than several thousand feet, but the general pattern which they show is the best measure now available of the total thickness of sedimentary rocks.

REFLECTION-SEISMOGRAPH SURVEYS

The very extensive reflection-seismograph surveys are not very suitable to the present designed to yield information to a depth about the same as that of the deepest wells.

Data from seismic surveys made at different times in separate but adjacent or near-by projects can be assembled into continuous subsurface profiles. Through the courtesy of three oil companies, three such profiles have been assembled, each showing reflection-seismograph data together with subsurface geological data from deep wells. (*See* Figure 1 for locations of these sections.)

Section No. 1 (Fig. 2), across eastern Texas from just south of the Red River southward to the coast, shows the east Texas basin at wells 3 and 4; southward from well 6, the dip is lar to that of Figure 2. The entire section shows regional southward dip; at well 23, at the extreme south end of the profile, the dip is still strongly southward, increasing with depth, and

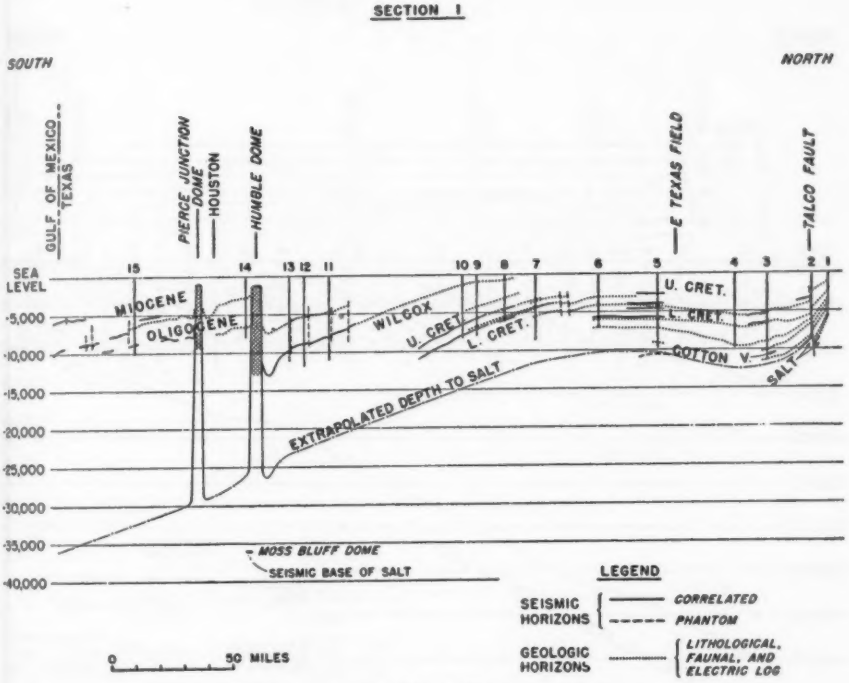

FIGURE 2.—SECTION NO. 1 (EASTERN TEXAS)
Showing subsurface correlations from selected deep wells and seismograph reflecting horizons.

toward the south all the way to the coast. The correlated seismograph horizons (shown by solid lines) and the phantom horizons (shown by dashed lines) fit in very well with the geological horizons from the well data (shown by dotted lines). The seismograph work adds detail between and below the wells and farther south than the last well. For the present problem, the most important indication is the extensive zone of south dip with a general steepening with depth and the lack of any indication of a synclinal reversal to the southern limit of the section.

Section No. 2 (Fig. 3), from southern Arkansas almost due south across the middle of Louisiana and a short distance into the Gulf of Mexico, shows a general situation very similar to that of Figure 2. The entire section shows regional southward dip; at well 23, at the extreme south end of the profile, the dip is still strongly southward, increasing with depth, and again there is no indication that a synclinal axis is being approached.

The gravity profile from the regional gravity map (Nettleton, 1949) is included on this profile. The axis of the regional minimum across south Louisiana crosses this profile approximately at the location of well No. 17, and the subsurface data give no confirmation to the suggestion that the gravity axis represents a regional syncline.

Section No. 3 (Fig. 4) shows seismograph control from a point near Natchez, Mississippi, and extends southward across the delta region of Louisiana to the coast. It also shows regular southward dip with no indication that a synclinal axis is being reached. This section has been extended northward, along the Mississippi

River (Fig. 1) to well 1-A, near the northeast corner of Louisiana, which reached the salt. The subsurface relations north of well No. 1 are generalized, as the well and seismograph data of that area are complicated by several salt-dome structures. This approximate connection indicates the relation of the salt to the drilled section farther south.

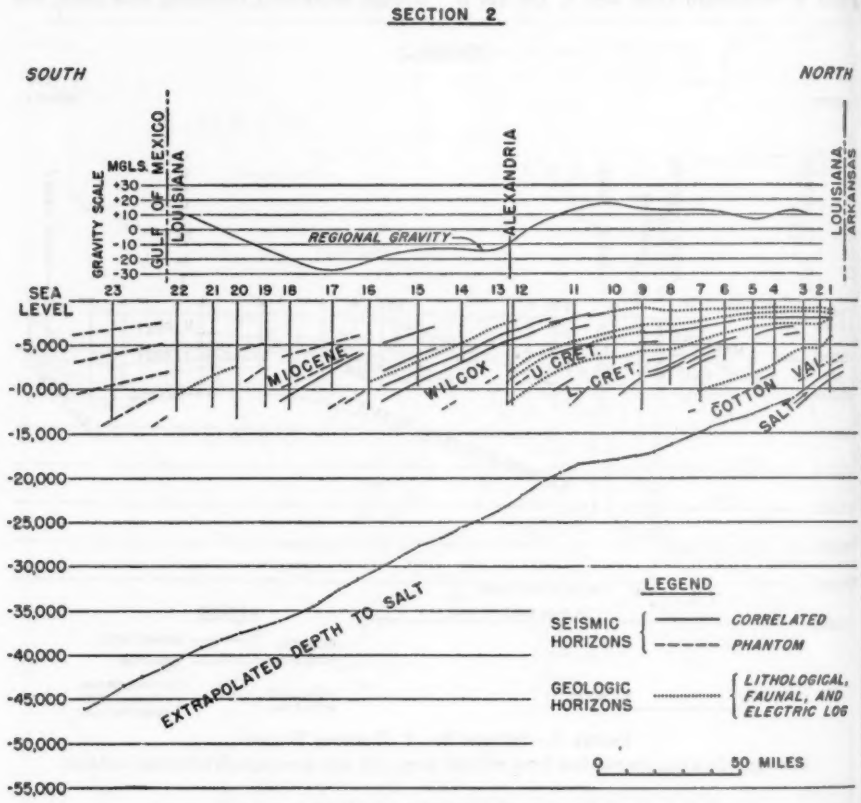

FIGURE 3.—SECTION NO. 2 (CENTRAL LOUISIANA)
Including regional gravity profile from 10 mg. contour gravity map (Nettleton, 1949).

INTERNAL REFLECTIONS IN SALT DOMES

In special cases, reflection-seismograph operations over shallow salt domes yield long-delayed reflections after quiet intervals; these can be interpreted reasonably as reflections from the base of the salt column. Three such instances are available.

In the Mississippi salt-dome basin, examples of internal reflections on the D'Lo and Arm domes (Fig. 1) have been published by Swartz (1943). The indicated salt depths were approximately 26,000 feet at the D'Lo dome and approximately 23,000 feet at the Arm dome. Similar reflections from the Moss Bluff dome in southeastern Texas have been published by Holyman (1946). If a relatively shallow reflection (which, from later considerations, may be attributed to a lateral discontinuity) is ignored, the indicated depth to the base of the salt column is approximately 36,000 feet.

These values for the depth to the base of the salt column probably should be considered tentative at this time and until many more in-

stances of such measurements are available, but they are considered of some value as a direct indication of the depth of the base of the salt layer.

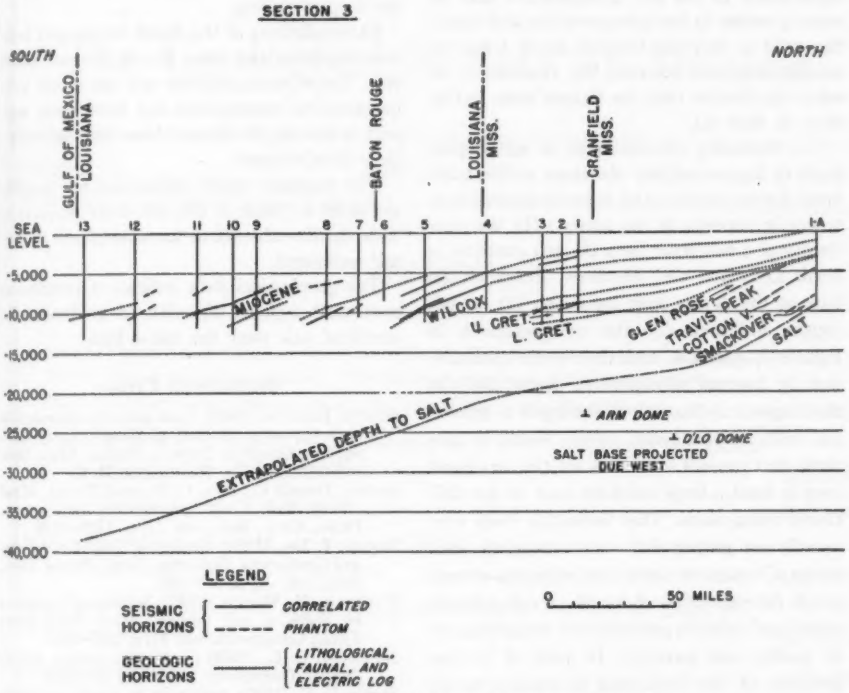

FIGURE 4.—SECTION NO. 3 (NEAR MISSISSIPPI RIVER)

DEPTH TO THE SALT

There have been many speculations as to the age and depth of the salt layer or layers from which the domes arise. From the salt contacts at the north end of each of the three profiles, we can make a crude extrapolation of a possible position of the salt, assuming that the various components of the sedimentary section persist unchanged in thickness toward the coast as they dip below any contact by the drill or reflection seismograph.

The curves for "Extrapolated depth to salt" on each of the three profiles have been constructed in this way. For instance, on Figure 2, the salt depth between wells 2 and 6 was plotted parallel to a horizon in the lowest geologic horizon (dotted line) shown, which is in the lower Cretaceous; from well 6 to a short distance beyond 9, the horizon near the top of the lower Cretaceous was used; from there to well 13, the horizon near the top of the Wilcox was used. The salt depth on the other profiles was extrapolated similarly.

The salt extrapolations are necessarily very uncertain, but they lead to depth values roughly in accordance with the depths from internal reflections in domes.

The salt depth in the Arm dome is 23,000 feet. Projected due west, this may be compared with the extrapolated salt depth on profile 3 (Fig. 4) at about 19,000 feet. With the uncertainties of projection and extrapolation, this may be as close an agreement as we can reasonably expect. The greater salt depth at the D'Lo dome, north of Arm, is inconsistent with the general pattern. It is possibly explained by the assumption of a relatively local salt basin in the general area of the Mississippi salt domes.

At the Moss Bluff dome, the reflection-

seismic salt depth is 36,000 feet which may be compared with an extrapolated salt depth of about 27,000 feet on profile 1 at well No. 14. This discrepancy is probably to be explained by uncertainty in the salt extrapolation and by some question in the interpretation and velocities used in deriving the salt depth from the seismic-reflection records. We consider it of some significance that the figures come out as close as they do.

The foregoing consideration of salt depths leads to figures roughly the same as the basement depths indicated by the calculations from magnetic surveys. If we accept: (1) the continuity of a salt layer from the salt contacts in north Louisiana and northeast Texas to the base of the domes near the coast, (2) the salt depths indicated by the extrapolations in Figures 2, 3, and 4, with their crude confirmation by internal reflections in domes, and (3) the magnetic indications of the depth to igneous and metamorphic rocks, we are forced to conclude that pre-salt sediments are thin or absent over at least a large southern part of the Gulf Coast embayment. This indication rests very heavily on geophysical data—magnetic estimates of basement depth and reflection-seismograph determination of length of salt columns which are sound in principle but unsatisfactory in quality and quantity. In view of the importance of this indication in relation to the general geological history of the area and the sources of Paleozoic sediments in adjacent areas, it is to be hoped that further geophysical determinations of the same kind may become available from existing or future geophysical records in the salt-dome area.

General Conclusions

The geophysical data have given at least nebulous indications of the general situation far below the depths of direct observations from the deepest drilling.

Extrapolations of the depth to the salt indicate depths at the coast line of around 40,000 feet. These extrapolations are made on very questionable assumptions but have some support in the depths derived from internal reflections in salt domes.

The magnetic depth indications are roughly the same as those of the salt-layer projection. This signifies absence or metamorphism of pre-salt sediments.

The geophysical data indicate a continuous coastward regional dip with no evidence of a synclinal axis near the coast line.

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ABSTRACTS OF PAPERS SUBMITTED TO THE NOVEMBER MEETING IN BOSTON, MASS., NOVEMBER 13-15, 1952

SOME ASPECTS OF THE GEOCHEMISTRY OF URANIUM

John A. S. Adams
University of Wisconsin, Madison, Wis.

New abundance of uranium data based upon analytical results from the University of Wisconsin demonstrate the soundness of the uraniferous province concept for common rock types. British workers also report uraniferous provinces in which all rock types tend to be higher in uranium content. Until the distribution and extent of uraniferous provinces are well known, it will be difficult to arrive at average abundance figures for common rock types. Aside from the province concept other difficulties arise in sampling and analytical errors.

Radiometrric and fluorimetric analyses showed that thorium tends to be separated from uranium in the sedimentary cycle. This is believed to be caused by the oxidation of U^{+4} to U^{+6}, perhaps in the form of UO_2^{+2}. This oxidation proceeds at a potential somewhat less than the oxidation of Fe^{+2} to Fe^{+3}. The uranyl ion is much different in charge and radius from Th^{+4} and would tend to become separated from it. The presence of iron in the ferrous state is probably a good indication that any uranium present is in the tetravalent state, and in this state it is diadoch with Th^{+4} and Zr^{+4}. This last conclusion is supported by the fact that thorium and uranium are usually associated in plutonic rocks, and these rocks have much of their iron in the ferrous state.

The uranium content of volcanics has received special attention, and it seems to be governed first by the general content of the province and second by the silica content. These conclusions are only tentative, however. Most pyroclastics are unique among primary rocks in that they have a very large surface area that makes them particularly susceptible to leaching. The role of this leachability in the geochemistry of uranium is under study.

COMPARISON OF THE CHEMICAL ANALYSES OF SEDIMENTARY AND METAMORPHIC ROCKS*

Arden L. Albee
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The composition of a metamorphic rock is commonly compared with that of the supposed parent rock to determine if chemical changes have taken place during metamorphism. Chemical analyses of metamorphic rocks supposedly derived from sedimentary rocks are frequently compared with composite analyses of sedimentary rocks (commonly Clarke's), and certain compositional features are compared with those that have come to be accepted as generally characteristic of sediments. E. S. Bastin has cited the dominance of MgO over CaO, the dominance of K_2O over Na_2O, an excess of Al_2O_3 over the amount necessary for feldspars, and a high SiO_2 content as characteristic of pelitic sediments. These generalizations concerning pelitic sediments have come to be regarded by many geologists as applicable to sediments in general, and some recent textbooks have so treated them.

Complete analyses of individual argillaceous and arenaceous rocks are presented graphically to show the range of variation from the composite analyses. The graphs also show the departure of various rocks types from the compositional features mentioned above.

Comparison of an analysis of a metamorphic rock with composite or averaged analyses of sedimentary rocks is shown to be an unreliable basis for hypothesizing chemical change during metamorphism. Comparison should instead be made with individual analyses of sedimentary rock, taking into account the geologic setting of the rocks to be compared.

Some of the important factors involved in the comparison of a sedimentary rock and its metamorphic equivalent are discussed.

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BEARING OF FORAMINIFERAL POPULATIONS ON LATE COMANCHEAN HISTORY OF NORTHEASTERN TEXAS

Claude C. Albritton, Jr., William W. Schell, Charles S. Hill, and John R. Puryear
Department of Geology, Southern Methodist University, Dallas, Texas

The unconformity separating the Comanche and Gulf series in Tarrant and Denton counties follows an irregular surface with local relief of several tens of feet. Although the rocks beneath the unconformity are of marine origin, ancient weathering profiles indicate that they were eroded subaerially before they were covered by the Woodbine sand. In reconstructing the history of this unconformity it becomes important to know whether the sequence of marine strata beneath it contains evidence of shallowing such as might represent a trend toward emergence.

At Grayson Bluff in Denton County the uppermost exposures of Grayson marl lie 14 feet vertically below the unconformity. Quantitative analyses of foraminiferal populations were made for 22 samples ranging through the exposed 66 feet of highly fossiliferous Grayson beds. Throughout the basal 64 feet, the principal benthonic families are variously the Buliminidae, Lagenidae, Rotaliidae, and Anomalinidae. These assemblages are similar to those Lowman found in the Gulf of Mexico between the middle continental shelf and upper continental slope. Within the upper few feet of the exposed section the benthonic fraction changes complexion remarkably and consists mainly of *Haplophragmoides* and *Ammobaculites*, agglutinated tests of the kinds Lowman found most abundant in very shallow waters near shore.

On this evidence one might conclude, however tentatively, that the Grayson marl preserves in its fossil record a trend toward shoaling which was the forerunner of emergence at the end of Comanchean time.

MINERAL AGE MEASUREMENT: MASS SPECTROMETRIC DETERMINATIONS OF Rb^{87} AND Sr^{87} IN LEPIDOLITES

L. T. Aldrich, J. B. Doak, and G. L. Davis
Dept. Terrestrial Magnetism, Carnegie Inst. of Washington, Washington, D. C.; Dept. Terrestrial Magnetism, Carnegie Inst. of Washington, Washington, D. C.; Geophysical Laboratory, Carnegie Inst. of Washington, Washington, D. C.

Isotopic determinations of Rb^{87} and Sr^{87} in lepidolites have been made using stable isotope dilution and mass spectrometric techniques. Chemical procedures outlined in the companion paper by Davis and Aldrich yielded sufficient Sr for this analysis if 2 grams of the lepidolite were available and it was as old as 10^7 years. Rb from 100 mg of lepidolite could be separated from the K with sufficient purity for isotopic analysis with a single recrystallization of the perchlorates. In the analysis of each mineral sample, 50 micrograms of Sr containing 64 per cent Sr^{84} and 180 micrograms of Rb containing 89 per cent Rb^{87} were added when the sample was first put in solution. The ratio Sr^{87}/Rb^{87} can be determined with a precision of 3 per cent under the least favorable conditions.

Ages have been determined in this manner for five lepidolites. They range from $158 \pm 10 \times 10^6$ years for a Pala, California, sample to $3300 \pm 300 \times 10^6$ years for a specimen from Southern Rhodesia. The absolute ages depend on the decay constant of Rb^{87}, the latest published value for which is $1.09 \pm .03 \times 10^{-11}$ year^{-1}.

X-RAY EVIDENCE OF THE NATURE OF CARBONATE-APATITE

Z. S. Altschuler, E. A. Cisney, and I. H. Barlow
U. S. Geological Survey, Washington, D. C.

The existence of carbonate-fluorapatite as a distinct variety of apatite rather than a mixture of a carbonate phase and fluorapatite has been tested by the following x-ray experiments: (1) Severa[l]

samples each of fluorapatite and hydroxyl-apatite, of approximately end-member composition, and of carbonate-fluorapatite (having 2 to 4 per cent CO_2) were x-rayed by powder-film methods under identical conditions of instrumentation and sample preparation. The resultant film patterns are distinctive and can be correlated visually with the above chemical types by reference to the (231) and (004) lines. (2) Mixtures of these several varieties were x-rayed, and line duplication resulted. (3) Mixtures of two samples of the same variety were x-rayed, and line duplication did not occur. (4) Unit-cell constants, computed from x-ray spectrometer patterns with an accuracy and precision of ±0.002A, offer proof that carbonate-fluorapatite is sufficiently different from fluorapatite and hydroxyl-apatite to be considered another variety of apatite. The cell constants follow:

	a_0(A)	c_0(A)	c/a
Hydroxylapatite, Holly Springs, Ga., U.S.A.	9.413	6.875	0.730
Fluorapatite, Durango, Mexico	9.386	6.878	0.733
Carbonate-fluorapatite, Staffel, Germany	9.344	6.881	0.736

The apatite in the marine phosphorites of Khouribga, French Morocco, of Florida and Idaho, U.S.A., and many other areas is carbonate-fluorapatite.

RECENT FORAMINIFERAL FAUNULES FROM THE LOUISIANA GULF COAST

Harold V. Andersen
Louisiana State University, Baton Rouge, La.

A taxonomic analysis of the Foraminifera incorporated with the sediments of Recent environments was undertaken to ascertain the environment of deposition of the clay in mudlumps that occur off the mouths of the passes of the Mississippi River, and the magnitude of vertical displacement of the mudlump clay.

The littoral environments contributed only negative information since the foraminiferal species present in the near-shore brackish-water sediments and in the inland bays and lakes were not present in the mudlump clays.

The neritic zone to the depth sampled (380 feet off the mouth of South Pass) contained species of *Nonionella*, *Strebulus*, and *Bulimina* which characterized most of the mudlump faunules. However, species of *Liebusella*, *Textulariella*, and *Vaginulinopsis* which characterize the foraminiferal faunules from other mudlump samples were not present in the neritic samples. Based on an examination of deep-water samples taken off the coast of Texas and Florida, this latter assemblage is living in water deeper than 380 feet and probably beyond the area of active delta growth. Therefore, the original area of deposition of the mud now constituting the clay of South Pass mudlumps carrying *Liebusella*, *Textulariella*, and *Vaginulinopsis* was in water deeper than 450 feet, and the vertical displacement of the clay in such mudlumps probably exceeds 400 feet.

MAGMATIC AND GRANITIZED ROCKS IN THE YELLOWJACKET DISTRICT, LEMHI COUNTY, IDAHO

Alfred L. Anderson
Department of Geology, Cornell University, Ithaca, N. Y.

The Precambrian Belt strata in the Yellowjacket district, Idaho, have been invaded by three unrelated groups of intrusive rocks, one of which has induced local granitization. The earliest group (pre-Cretaceous) is represented by small bodies of considerably altered gabbro; the second (late Cretaceous or early Tertiary) by dikes and stocks of diabase, olivine gabbro, augite-hornblende-biotite diorite, hornblende-biotite diorite, pegmatite, and lamprophyre, and marginal masses of biotite diorite and syenite about the body of hornblende-biotite diorite and a small dike of pulaskite

remote from the diorite; and the third (Miocene) by dikes and less regular bodies of granophyre, granite porphyry, and vitrophyre.

Except for the biotite diorite, syenite, and pulaskite, the rocks have all the textural and structural characteristics of quickly cooled hypabyssal intrusives, complete with various reaction phenomena and in part with micrographic and microspherulitic intergrowths. The exceptions are products of alkali-rich granitizing fluids from the hornblende-biotite diorite magma, with the biotite diorite and syenite formed by replacement of the bordering Belt rocks and the pulaskite by consolidation of the fluids along more distant channelways. Metallization accompanied the second group of intrusives, with ore deposition just ahead of the injection of lamprophyres, which brought the magmatic cycle to a close. The two earlier groups of intrusives apparently had their sources in the basic subcrust; the younger in magma that had reached a higher level in the crust. None of the intrusives is related to the deeply underlying Idaho batholith.

ANTARCTICA DRAINAGE PATTERN*

Earl T. Apfel
Syracuse University, Syracuse, N. Y.

The precipitation on Antarctica accumulates as ice on the land and drains from the land through glaciers. The glacial drainage pattern is in part controlled by the relief of the underlying rock and in part by the distribution of precipitation, resulting in the development of glacial drainage basins, continental divides, master streams of ice with their tributaries, and different volumes of flow from different basins.

An attempt is made to map the present drainage pattern of the Antarctic continent from the sizes of the outlet glaciers and their relative rates of flow as indicated by their crevassing, gradients, and shelf-ice debouchment; from the known distribution of land and the trend of structural units; from indicated regional wind patterns; and from the probable distribution of the accumulation of ice on the continent.

PITCHBLENDE DEPOSITS ON QUARTZ HILL, CENTRAL CITY DISTRICT, GILPIN COUNTY, COLORADO

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The Central City district, in the northern half of the Colorado Front Range mineral belt, has been the principal domestic source of pitchblende. A recorded 110,757 pounds of U_3O_8 has come from Quartz Hill—more than 98 per cent from the Wood and Kirk mines.

Quartz Hill is underlain by a folded sequence of Precambrian biotite granite gneiss, amphibolite, quartz-biotite schist, granulite, and skarn intruded by pegmatite, metagabbro, and Upper Cretaceous bostonite. These rocks are cut by steeply dipping, east-trending faults that contain metalliferous veins. The Central City district is zoned with pyritic gold ores in the center and lead-zinc-silver ores on the periphery. Quartz Hill is on the west side of the district and is in a transition zone where the mineralogy of the veins changes from quartz-pyrite-gold on the east to quartz-pyrite-sphalerite-chalcopyrite-galena-gold-silver on the west. Pitchblende occurs with chalcopyrite in this transition zone. Gold ore bodies are grossly controlled by the intersection of faults with brittle granitic layers, and pitchblende ore bodies probably have a similar control. Mineralogically and structurally the veins are of xenothermal type.

Ore produced from the Wood and Kirk mines had an estimated average grade of 0.2 per cent U_3O_8. Unmined parts of the Wood and Kirk veins within the transition zone probably contain ore of similar grade.

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LATE WISCONSIN MARINE DRIFT AND ASSOCIATED SEDIMENTS OF THE LOWER FRASER VALLEY, BRITISH COLUMBIA*

J. E. Armstrong and W. L. Brown
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During late Wisconsin time an assemblage of fossiliferous till-like stony clays and associated clay, silt, sand, and gravel up to 400 feet thick was deposited in the Lower Fraser River Valley of British Columbia. The authors believe that these sediments were deposited in the sea during and following the wasting and retreat of a major Cordilleran ice sheet, and during the subsequent period of uplift of the land above sea level. The agents of transportation probably were ice, including barrier, berg, and sea ice; glacial meltwater; and sea water. The writers believe the till-like stony clays, called glacial till by previous workers, had more than one origin, namely: (1) The stony clays are in part marine drift; that is, the stones and some of the finer materials were transported by ice, and the remainder of the finer materials, predominantly clay, were transported by meltwater and sea water. Three modifications of this theory suggest themselves depending largely on how the stones were tranported: (a) barrier ice theory, (b) berg ice theory, and (c) sea ice theory. (2) The stony clays were in part deposited by submarine erosion in the littoral and sublittoral zones from the action of submarine slides or slopewash, sea currents, and turbidity currents on pre-existing sediments during the uplift of the land following the maximum advance of the ice sheet. The authors have termed this the submarine slopewasb theory. The marine drift and submarine slopewash theories are combined in a composite theory which also explains the origin of the associated sediments.

STATUS OF SUMMARY COAL RESOURCE SURVEYS NOVEMBER 1952

Paul Averitt
U. S. Geological Survey, Washington, D. C.

Summary studies of coal resources are in preparation or in press covering seven States—Illinois by the Illinois Geological Survey; and Indiana, Virginia, Colorado, North Dakota, South Dakota, and Oklahoma, by the U. S. Geological Survey. Like other such statewide studies completed in recent years, these studies show a continuation of the trend toward a reduction of the estimates of original reserves.

Based on the latest available figures for individual States, the original coal reserves of the United States total about 2 trillion tons as compared with M. R. Campbell's estimate of 3.2 trillion tons. This difference is due primarily to the more conservative method used in preparing the new State estimates, which are on a bed-by-bed basis as contrasted with Campbell's regional basis.

The total original reserves in the United States thus appear to grow successively smaller as the new conservative State summary studies are completed. Because many of the newer State estimates are rock-bottom, minimum estimates based on incomplete data, it is apparent that the total United States reserves, when finally appraised at the conclusion of the current program, will be the minimum known reserves, and the figure will be subject to increase as mapping and exploration are continued.

RADON LEAKAGE FROM RADIOACTIVE MINERALS

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The rate of radon leakage from selected radioactive minerals and ores has been measured as a function of particle size and temperature. The results indicate that the leakage process is due to

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diffusion of the gas through microfissures in the mineral, and that, when steady state conditions are reached, the leakage at temperatures up to 200°C. does not differ appreciably from that at 25°C. Theoretical considerations, supported by experimental evidence, indicate moreover that the leakage is essentially independent of hydrostatic rock pressure.

Conclusions which seem warranted from the preliminary studies described are:

(1) Leakage rates for pitchblendes may be as high as 5%, from .1% to .5% for uraninites, .01% to .1% for samarskites.

(2) Laboratory measurements of radon leakage give a good first approximation of the leakage for the entire history of the mineral.

(3) The Pb^{207}/Pb^{206} age is very sensitive to radon leakage in the low time range, and in general the Pb^{206}/U^{238} age is more accurate.

PLEONASTE FROM CABALLO MOUNTAINS, NEW MEXICO

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Pleonaste crystals occur as large phenocrysts in several nepheline-olivine basalt flows at the north end of the Caballo Mountains, New Mexico. These Quaternary (?) flows overlie Cretaceous and Permian strata and are separated from them by an angular unconformity.

The pleonaste spinels from this area range from microscopic up to 15 mm. across. Most of the pleonaste crystals are anhedrons or malformed octahedrons. Good octahedrons, or octahedrons truncated by dodecahedrons, are not uncommon, and one cubic truncation has been noted. The octahedron faces are usually pitted. The color is dark green to brownish green, nearly opaque; fracture, conchoidal; luster, dull on external surfaces, vitreous to splendent on fractures; hardness, 8; parting, cubic. The measured specific gravity ranges from 3.83 to 3.88; calculated specific gravity is 3.91. The space group is Fd3m, $a_0 = 8.12$ Å. The index of refraction ranges from 1.788 to 1.789. The empirical formula, as determined from a chemical analysis of 4.025 gm, is:

$$(Fe_{.21}Mg_{.63})O \cdot (Fe_{.02}Al_{1.93})_2O_3.$$

From petrographic studies it is concluded that the original mafic magma, before eruption, cooled and remained uniform long enough to allow large crystals of pleonaste and olivine to form, then was ejected and cooled too quickly for the liquid to reabsorb these early-formed crystals.

PLEISTOCENE COMPLEX IN THE NORTHERN RIM OF THE SOUTHERN PENINSULA OF MICHIGAN

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Wastage of the Mankato ice from its end position on the main ridge of the Port Huron moraine was accompanied by a succession of short retreats, stillstands, and readvances followed by final dissipation toward the close of the Wisconsin stage. The recurrent adjustments of the ice border, no doubt, were responsible for the development of the multiple ridged character of the morainic system and for the concentration of drumlins on both the Lake Huron and Lake Michigan slopes of the Mankato drift surface.

In the intervals of excessive melting, large volumes of sediment-charged water derived from the ice front were sluiced through drainways to form well-defined spill-plains and extensive outwash aprons. That many of these drainways were partially filled with ice during melt water discharge is evidenced by the presence of kame terraces developed along their margins.

During the sequence of events that resulted in the development of Lake Algonquin and Nipissing which followed, much of the area was modified by waters that encroached upon the lowland marginal tracts. Well-defined cliffs and strong wave-built shore features, which may be traced uninterruptedly

for hundreds of miles along the rim, support the view that the occupancy of these lakes was of fairly long duration. The successive lowering of the lake levels, together with the adjustments related to crustal warping and differential uplift, exposed wide stretches of sandy strand that provided material for further modification of the surface by aeolian activity.

STUDIES OF METAMICT MINERALS (II): RE-EXAMINATION OF FERGUSONITE

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With one possible exception all descriptions of fergusonite found by the author indicate that the mineral occurs only in the metamict state.

In 1926, T. F. W. Barth investigated this problem. He concluded that the mineral crystallizes at about 400°C., but the crystallized particles are too small for good x-ray diffraction unless heated to 800°C.–900°C.

My investigation shows that fergusonite is dimorphic. At approximately 450°C. metamict fergusonite crystallizes and can be indexed with orthorhombic axes. At higher temperatures (ranging from about 850°C. to 1050°C., depending on the kind of sample and the length of heating time) it crystallizes in a form identical with that of synthetic "fergusonite". Barth has indexed this synthetic "fergusonite" with a tetragonal lattice.

It is believed that the structure of the low-temperature dimorph of fergusonite is equivalent to the structure of the original crystalline material.

NEW DATA ON LEAD SULPHARSENIDES FROM BINNENTAL, SWITZERLAND

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Weissenberg and precession camera studies on baumhauerite, dufrenoysite, and rathite lead to the following new structural data:

Baumhauerite is triclinic (pseudomonoclinic) with $a = 22.74$, $b = 8.33$, $c = 7.89$A, $\alpha = 90°$, $\beta = 97°25'$, $\gamma = 90°$. The unit cell contains 4 [3 $PbS.2As_2S_3$].

Dufrenoysite is monoclinic, probable space group P^2_1/m; $a = 8.41$, $b = 25.85$, $c = 7.88$A, $\beta = 90°30'$. The unit cell contains 8 [$2PbS.As_2S_3$] with specific gravity 5.53 (measured), 5.61 (calculated). The axial ratio of the unit cell, $a:b:c = 0.326:1:0.306$, agrees closely with the ratio given by Palache (Dana, 1944).

Rathite-II is monoclinic, probable space group P^2_1/m; $a = 8.32$, $b = 70.9$, $c = 7.91$A, $\beta = 90°$. The unit cell probably contains 2 [$19PbS.13As_2S_3$] with specific gravity 5.42 (measured, Jackson), 5.52 (calculated). The unit cell dimensions do not agree with previous structural or morphological data on rathite, although they were obtained on a fragment of the original material analyzed by Jackson (analysis 3, Dana, 1944) which was kindly supplied by Doctor Bannister from the British Museum (Natural History).

GROWTH OF ICE-WEDGE POLYGONS IN PERMAFROST NEAR BARROW, ALASKA

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Measurements of thermal contraction and of rate of growth of ice-wedge polygons near Barrow, Alaska, during the winter of 1949–1950 support Leffingwell's contraction hypothesis for their origin. Maximum and average ranges and median and mean values of thermal coefficients computed from measurements between vertical rods in silt, fine sand, and clay approximate the coefficient of expansion of pure ice (51×10^{-6}). The values for gravel become progressively smaller as moisture content and sorting coefficient decrease.

Noncumulative errors of measurements and errors due to tilt or heave of rods and to lack of adequate temperature records prevent use of absolute values. Nevertheless, means of observed coefficients approach theoretical coefficients computed from measured ground temperatures and soil moisture. Most of the active layer in winter and the upper part of permafrost throughout the year is a suspension of solids in ice.

To determine the rate of growth of ice-wedge polygons the following sites were excavated: an old high-centered area with three generations of wedges, a young high-centered area, and a young low-centered area in silt, fine sand, and clay; and an old high-centered area with two generations of wedges in an uplifted gravel bar. During the winter 37, 65, 58, and 46 per cent respectively of the wedges cracked. The width of ice filling in the cracks averaged 1 to 3 mm. Average widths of first-generation wedges in each site approximate 2.5 m, 1.5 m, 1.3 m, and 1.5 m. If uniform growth is assumed, the indicated age of the coastal plain at Barrow ranges from 1000 years in younger to 3500 years in older areas.

The project was sponsored jointly by the U. S. Geological Survey and the Office of Naval Research, with headquarters at the Arctic Research Laboratory.

RELATIONSHIP BETWEEN LIGHT ABSORPTION AND COMPOSITION IN A SOLID-SOLUTION SERIES

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Using a spectrophotometer improvised from a monochromator, polarizing microscope, and a photomultiplier tube, light-absorbance measurements were made for the γ' direction on a (110) face for crystals of varying nickel content in the solid-solution series between Ni $(NH_4)_2(SO_4)_2 \cdot 6H_2O$ and Mg $(NH_4)_2$ $(SO_4)_2 \cdot 6H_2O$. Measured absorbance values confirm the Beer-Lambert law within the limits of measurement. On the basis of this law, compositions predicted from absorbance per centimeter values of different crystals were, on the average, accurate to within 2.5 mol per cent (of the compositions predicted from density values).

Calculations to obviate the effects of opaque inclusions and internal cleavages in the measured crystals when predicting composition from absorbance measurements are discussed.

LITHOLOGY OF THE STANLEY AND JACKFORK FORMATIONS, OUACHITA MOUNTAINS, ARKANSAS AND OKLAHOMA

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The Stanley and Jackfork formations (Late Mississippian-Early Pennsylvanian) constitute the thick, orogenic-phase filling of the Ouachita geosyncline. They attain a maximum thickness of 15,000–20,000 feet compared to 3000 feet of Cambrian through Mississippian sediments, and supposedly were derived from Llanoria, a borderland to the south.

The Stanley formation consists of approximately 61% soft, irregularly fissile, and laminated, siliceous shale, 32% fine-grained graywacke, 7% siltstone, and several tuff beds. Graywacke beds, ranging from 1 to 91 inches in thickness, and shale zones, from 1 inch to 24 feet thick, are rhythmically interbedded. Cross-bedding and ripple marking are rare, but grading is suggested. Lack of reworking, evidenced by the clay content of the graywackes, uniformity of lithology, and absence of ripple marking and cross-bedding, indicates deep-water deposition. Turbidity currents of high density are proposed as a possible mechanism of emplacement.

The conformably overlying Jackfork formation contains approximately 70% fine- to medium-grained quartzites, 27% shale, and 3% siltstone. Thick zones of sand are separated by thinner shale units. Ripple marking, small-scale cross-bedding, and scour markings are common. Cleanness of the

sands and presence of agitated water structures suggest deposition in shallow water over a rapidly subsiding substratum.

The change from deep- to shallow-water deposition that occurred during Stanley and Jackfork time was paralleled by an analagous change in the source of the sediments. Both are closely related to the structural evolution of the geosyncline.

PUNCHED-CARD BIBLIOGRAPHY FOR COAL

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Within recent years the literature concerned with coal has grown so rapidly that it has become difficult to assemble and correlate the available information. In an effort to organize in the most easily accessible form a large amount of data with regard to the geological, biological, and chemical factors active in the formation of coal, along with information on the analysis and structure of coals and components of wood, a hand-sorted punched card file has been prepared. The preparation of the code for the cards will be discussed, and the use of the cards will be demonstrated.

The excellent bibliography on coal which was recently distributed by Mr. Horace Miller should serve as a starting point for future work. Several methods will be proposed by which it is hoped that the scope of an annual bibliography on coal can be expanded to include such subjects, among others, as mining and product preparation. The advantages of an annual bibliography prepared jointly by a group of interested persons and presented in a form where facts can be correlated is very appealing. Several suggested working methods will be proposed for the use of punched cards in a co-operative program.

DEPOSITION OF UPPER CRETACEOUS SEDIMENTS, DIABLO RANGE, CALIFORNIA

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Upper Cretaceous rocks in the Diablo Range, California, comprise a thick prism of clastic geosynclinal sediments that total more than 30,000 feet in thickness near Panoche Hills. The predominant and characteristic rock of this sequence is shale intimately bedded with thin partings of feldspathic sandstone ranging in thickness from a fraction of an inch to several tens of feet. Other rock types include shaly sandstone, coarse conglomerate, arenaceous and argillaceous limestone, and foraminiferal and radiolarian clay shale.

Previous investigators have interpreted the thinly laminated sandstone and shale, the coarse conglomerate, the common shale and siltstone pebbles, and the relatively rare neritic macrofauna to indicate deposition near wave base in a shallow marine basin. However, deep-water deposition is strongly suggested by slump structures, crinkled bedding, pelitic fragments, broken and transported macrofauna, deep-water Foraminifera, and the lack of shallow-water sedimentary structures such as ripple marks, cross-bedding, and channeling and scouring in the extensive conglomerate strata. Only a minor proportion of the sedimentary sequence, those beds at the base and at the top of the section, can be ascribed with certainty to a shallow-water depositional environment.

CHARACTER AND ORIGIN OF THE ROAN AND CAROLINA GNEISSES IN THE SPRUCE PINE PEGMATITE DISTRICT, NORTH CAROLINA

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A belt of upper-middle-grade metamorphic rocks that has long been divided into the Roan gneiss (essentially hornblende gneiss and schist) and the Carolina gneiss (essentially mica gneiss and schist)

constitutes a part of the Spruce Pine pegmatite district in the Blue Ridge of western North Carolina. Detailed field mapping of 250 square miles indicates that these two rocks are interlayered and that the individual layers range from about an inch to several tens of feet thick. The hornblende and mica rocks merge laterally and vertically.

All the metamorphic rocks have been plastically deformed into complex folds. Foliation parallels the layers. No crosscutting relationships have been found between the two gneisses.

The mica rocks include mainly biotite and muscovite gneiss and schist. The feldspar is generally oligoclase; orthoclase and microcline are rare. The schists typically have more mica, with muscovite dominating over biotite; they also have more garnet and are more distorted than the gneisses. Typical accessory minerals in the Carolina gneiss are garnet, staurolite, kyanite, epidote, allanite, apatite, zircon, and magnetite-ilmenite.

The hornblende rocks are chiefly gneiss and schist which, in addition to the hornblende, contain quartz, andesine, epidote, and magnetite-ilmenite. Associated rocks include layers rich in actinolite, epidote, zoisite, garnet, diopside, and rarely dolomite.

Field evidence and laboratory studies suggest that the Roan-Carolina complex is of sedimentary origin. The Roan gneiss may have been derived from ferruginous calcareous shales and dolomitic limestones, the Carolina gneiss from clayey to sandy shales and sandstones.

SOME ASPECTS OF THE GEOCHEMISTRY OF POTASSIUM, RUBIDIUM, CESIUM, AND THALLIUM IN SEDIMENTS

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Determinations of the rubidium, cesium, and thallium contents of 323 samples from 10 sedimentary geological formations have been made by spectrochemical methods. Potassium, present as a structure constituent in a known concentration, was used as a variable internal standard. The precision of the spectrochemical methods employed, expressed as standard deviations, was $\pm 4.5\%$ for rubidium, $\pm 8.2\%$ for cesium, and $\pm 8.8\%$ for thallium. Average abundance values for these elements in argillaceous sediments are: Rb_2O — 0.031%, Cs_2O — 0.00081%, and Tl_2O — 0.000038%. Thallium is usually enriched in highly organic sediments.

The average % K_2O/% Rb_2O, % K_2O/% Cs_2O, % K_2O/% Tl_2O, and % Rb_2O/% Tl_2O abundance ratios in the various classes of sedimentary materials will be given and their significance discussed. A comparison of these values with the average values of corresponding ratios in igneous rocks shows that the order of relative enrichment of these elements in sediments is normally: Cs > Rb > K > Tl.

It is concluded that the order of relative enrichment found is in excellent agreement with the theory that the adsorption affinity of a cation from aqueous solutions is proportional to the value of the positive electrostatic potential existing at the surface of the hydrated ion.

HISTORY AND CAUSES OF RISING WATER LEVELS IN THE RECHNA DOAB, PUNJAB, WEST PAKISTAN

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In a study conducted under the auspices of the Food and Agriculture Organization of the United Nations and the Government of Pakistan, the writer studied the ground-water conditions of the Rechna Doab in the Punjab. Here a high water table over much of the Doab is contributing to deterioration of agricultural lands through salt accumulation.

The sediments underlying the Doab are typical river deposits of the Indus system consisting of coarse to find sand, silt, and lenticular clay beds, capped by a generally continuous silt and clay deposit up to 40 feet thick. A range of old hills of Archean rocks projects through the sediments at three points in the Doab.

The ground-water table of the Doab began rising in 1882, when the first irrigation canal was opened. In a large area of the central part of the Doab, where the water table was, in general, 30 to 80 feet below the land surface in 1882, ground-water levels are now within 10 feet of the surface. Where the water table in 1882 was 80 to 96 feet below the land surface, the water table is still 20 to 33 feet below the land surface, but is rising at the rate of 1.5 to 2 feet per year.

Maps of the water table in 1920 and 1950 indicate that the principal cause of rising ground-water levels is seepage from unlined canals. Infiltration of irrigation water also contributes.

RELATIONSHIPS OF THE CARPOID ECHINODERMS IN THE LIGHT OF *ENOPLOURA*

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Exceptionally complete specimens of *Enoploura*, an American Upper Ordovician carpoid echinoderm, demonstrate the validity of the hitherto suppressed genus. In the light of this new knowledge a complete restudy of the world Carpoidea seems profitable. Of paramount importance in the recognition of carpoids, *s.s.*, and in their ecology and classification is the *stylocone organ* of both locomotion and temporary fixation. The very existence of this organ has been generally overlooked in American studies, although first described in detail by Wetherby from Cincinnatian materials in 1879.

The resurvey of the Carpoidea raises again the question of the nature of carpoid symmetry, and the degree, if any, to which pentaradial, or any radial symmetry enters into the morphology of the group; likewise the homologies commonly drawn between the plates of the carpoid calyx and other echinoderm skeletons, and the consequent right-left and dorso-ventral orientation.

Several new families and genera of carpoids are proposed, and the broad evolutionary history of the group traced. It appears that previous classifications of the Carpoidea have inadvertently included homeomorphic cystoid lineages.

The genus *Enoploura* demonstrates a surface ornament pattern so reminiscent of that well known in ostracoderms as to fortify still further the argument of common ancestry of the Carpoidea and the Chordonia.

Two new Lower Devonian carpoids from Brazil are introduced and compared with coeval forms from South Africa.

ORIGIN OF GRANITIC GNEISS DOMES OF WESTERN NEW HAMPSHIRE

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Investigators have mapped and described at least 12 domical structures within a narrow belt in western New Hampshire. Each dome consists of an elliptical core of weakly foliated gneiss, mantled by concentric belts of metamorphosed sedimentary and volcanic rocks. The foliation of the gneissic core is most pronounced near the borders where it parallels the contact and the bedding-plane schistosity of the adjacent metamorphic rocks.

Various magmatic origins have been proposed for these Oliverian domes including the laccolithic, phacolithic, and sill theories. Virtually no consideration, however, has been given to other possible origins. That metamorphic and metasomatic phenomena may have played dominant roles in the formation of these gneissic domes seems highly probable and warrants special attention. This possibility is discussed, and evidence for replacement in the dome rocks is given. The time and space relation of the Oliverian domes to the general sequence of tectonic and petrologic events in central New England is considered to have a most significant bearing on the origin of the domes themselves.

It is tentatively concluded that, whereas many observations may be interpreted as indicating a magmatic origin for the gneissic cores of the Oliverian domes, our present knowledge of these plutons may be explained more logically by the metamorphic-metasomatic theory.

BORDERLANDS OF THE WESTERN PACIFIC*

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Indonesia, the Philippines, Formosa, the Ryukyus, and Japan provide stratigraphic, structural, physiographic, and biotic evidence of former continuity with Asia.

The Mariana arc, east of the Philippine Sea, resembles the older Ryukyu arc. Both consist of an outer row of mainly older Cenozoic islands and an inner row of young volcanoes. Both are bordered to the east by a submarine trench. Available evidence indicates that the Mariana trench coincides with a belt of negative gravity anomalies and suggests that similar relationships will obtain for the Ryukyu trench. This pattern differs from Indonesia, where negative anomalies coincide with an outer non-volcanic ridge bordered by trenches.

That the approximate boundary between the Asiatic structural block and the true Pacific Basin is nearly located by the Palau-Yap-Mariana-Japan trench system is indicated by (1) gravity anomalies; (2) distribution of earthquake foci; (3) abundance of andesitic rocks in but not beyond the outer island arcs; (4) similar restriction of metamorphic, plutonic, and highly silicic rocks; and (5) submarine topography. In the Pacific Basin proper, approximate gravimetric compensation prevails; seismic inactivity is the rule; oceanic basalts are abundant and andesites rare; plutonic metamorphic and highly silicic rocks are unknown; and narrow trenches and ridges are rare.

The Philippine Sea is properly a deep epicontinental sea and structurally a part of Asia. Whether it has long been a part of Asia, or is only in the process of being added to a growing continental block, is a major problem. The origin of the negative anomaly belts and island arcs is also moot.

ISOTOPIC CONSTITUTION OF RADIOGENIC LEADS AND THE MEASUREMENT OF GEOLOGICAL TIME

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The authors review the age determinations carried out by them. Isotopic abundances and ages are listed for more than 70 radiogenic leads extracted from uranium-bearing samples. Chemical analyses are given for some of the samples. Ages have been calculated from ratios of radiogenic Pb^{207}/Pb^{206}, and from the ratio of Pb^{206}/U^{238} for chemically analyzed samples.

The reliability of the chemical and isotopic ages is discussed. Discrepancies between the ages by the two methods may be explained by the loss of uranium or lead in recent time which may occur by partial dissolution or alteration of the sample. Evidence shows that the loss of radon is small or does not occur and that therefore the isotopic age values are the most reliable, as Nier pointed out.

From age determinations plus mineralogical evidence the behaviour of hydrothermal pitchblende deposits is discussed. Evidence is given of the dissolution and redeposition of such deposits. Ages of uraninites and of a few pitchblendes are considered useful in dating orogenies, but many pitchblendes give younger dates for that reason.

The preparation and analysis of samples are described. Quantities of lead as small as 5 mg. have proved sufficient for the preparation of adequate samples of lead tetramethyl for analysis in a mass spectrometer.

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ISOTOPIC CONSTITUTION OF ORE LEADS AND THEIR RELATION TO GEOLOGICAL TIME

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Since the publication of Nier's determinations of the isotopic constitution of leads from lead ores of different ages, his data have been the basis for several estimates of the age of the earth's crust and of the maximum time of formation of the elements. All these investigators have pointed out the need for more isotopic analyses of naturally occurring leads of known age. The authors report the isotopic constitution of 14 samples of lead ores, 12 of which were collected from Precambrian areas. A number of these leads have been dated, by isotopic analyses of associated radiogenic leads by the authors, by isotopic analyses of radiogenic leads by Nier, and by Ahren's ages from the Rb-Sr method. These new values for the isotopic constitution of ordinary leads have been combined with those of Nier and used to calculate the time of solidification of the earth's crust, for which the authors report a value of 3.5 ± 0.2 billion years. This value agrees with estimates reported by Holmes, and by Bullard and Stanley within the limits assigned. A new estimate of 5.50 ± 0.2 billion years is given as a maximum limit for the time of formation of the elements.

The authors discuss the dating of ore leads from their isotopic constitution, and point out that, while no general criterion may be used for all samples, it is usually possible to date approximately the separation of the ore from the parent magma.

SUMMARY OF TWO CONFERENCES ON PROBLEMS OF DUNKARD STRATIGRAPHY AND RESULTING INTERPRETATION

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The ideas and opinions expressed at the Field Conference "On the Stratigraphy, Sedimentation and Nomenclature of the Upper Pennsylvanian and Dunkard Strata" and at the Round Table Conference in Washington are summarized and contrasted. The interpretation of these suggestions as integrated with the specific problems encountered in the area under consideration are given.

The entire sequence of strata is divided into cyclothems, and several cyclothems are grouped as a formation. The position of the base of the coal-top of the underclay is the dividing line between successive cyclothems. A number of Dunkard and Monongahela coal seams may be correlated on the basis of plant microfossils, and a number of examples of the results of this work are illustrated.

Additional information now available for the southern part of the Dunkard Basin is given. This includes especially the great increase in percentage of the total thickness of rock of the red shale component of the cyclothems and in facies of this type; most of the members of the cyclothems gradually disappear until red shales and impure sandstones occupy virtually the entire thickness. In such areas cyclothems are difficult to ascertain and virtually impossible to differentiate on the basis of any information or characters now available. Intervals from persistent coals are the only evidence found useful at present.

LATERAL DISPLACEMENT ON THE SAN GABRIEL FAULT, SOUTHERN CALIFORNIA

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The San Gabriel fault zone, which trends northwesterly subparallel to the San Andreas fault for about 90 miles, appears to have a post-late Miocene right-lateral displacement of 15–25 miles. South-

west of the nearly vertical fault, 6 miles northwest of Castaic, Los Angeles County, upper Miocene coarse conglomerates grade southwesterly into finer sediments from their source, now disappeared, across the fault to the northeast. The conglomerates, which contain boulders of anorthosite and norite, were derived from a near-by basement terrane containing these rock types. A buried source is eliminated because at present *all* basement rock known across the San Gabriel fault from the conglomerates for several miles to the northeast is covered by sedimentary rocks *older* than the conglomerates. Basement types exposed still farther northeast do not include anorthosite and norite. In fact, the only occurrence *in situ* of these rock types known in the entire region is in the San Gabriel Mountains 23 miles southeast of the conglomerates and on the other (northeast) side of the San Gabriel fault zone. Clearly, then, this was their source area, and the conglomerates have been displaced 15–25 miles relatively northwest.

Large right-lateral displacement is also suggested by the presence of upper Miocene sedimentary breccia now found northeast of the fault about a mile northwest of Castaic. This breccia, containing blocks of gneiss almost exclusively, has been offset from its apparent source now at least 6 miles but probably 15 miles or more to the northwest.

MINERAL AGE MEASUREMENT: CHEMICAL SEPARATION OF RB AND SR BY MEANS OF ION-EXCHANGE COLUMNS

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The chemical separation of trace amounts of any element, in pure form, from minerals is a formidable problem by conventional analytical procedures. For mineral-age measurements by mass-spectroscopic analyses it is particularly important to obtain strontium, rubidium, and calcium from micas, feldspars and accessory minerals from granites. The strontium must be completely separated from rubidium and usually partially separated from calcium.

Ion-exchange resin columns have been adapted to this separation and procedures developed in which, first, the alkali metals and alkaline earths are completely separated from the aluminum, iron, zirconium, and other elements in the mineral, with complete recovery. Next, the alkalis are removed from the column, separated partially from each other and completely from the calcium and strontium. Finally the alkaline earths are removed with at least a partial separation.

TEXTURAL RELATIONSHIPS IN THE SALINA SALT OF MICHIGAN

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Petrographic examination of the salt bed at the base of the Salina was directed toward the study of the textural relationship between halite, anhydrite, and dolomite and related pyrite, sylvite, celestite, quartz, and carbonaceous material. The core examined was taken from Newago County, Michigan; the base of the salt was intersected at 5147 feet. Study of these relationships was facilitated by the frequent interbedding of dolomite and anhydrite with salt in the lower portion of the section.

Some of the particularly significant relationships are (1) variations in grain size and shape of dolomite and anhydrite, both tending toward increased size and euhedral shape in the presence of halite, (2) reversal of the normal sequence of deposition with changes upward progressing from salt to anhydrite to dolomite to salt, (3) concentration of pyrite and carbonaceous material along the contact between halite and the overlying anhydrite, (4) brecciation of anhydrite layers, the fragments being contained in a matrix of dolomite, and (5) development of a chevron structure in halite due to the orientation and concentration of liquid inclusions in the form of negative crystals.

DIRECTIONAL LAPPING HARDNESS IN DIAMOND

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To measure the relative variation of grinding hardness in single diamond crystals two devices have been constructed. One, which might be called a hardness comparator, permits the cutting of two crystals simultaneously. One crystal is oriented in an arbitrarily chosen unit hardness direction. The cutting rate of the second crystal is compared with the cutting rate of the reference crystal.

To facilitate the measurements a second apparatus has been designed to prepare spherical surfaces of predetermined radii on the diamonds. This apparatus was used in connection with hardness-variation measurements on the cube face. The remainder of the planes investigated were studied on pyramidally faceted stones, because of the very slow operation of the sphere grinder.

Hardness curves were plotted, hardness against grinding azimuth, for the cube, dodecahedron, and octahedron, and for intermediate planes in the zones containing these three planes.

Hexoctahedral symmetry was assumed since no evidence of lower symmetry has been obtained from hardness measurements.

Errors inherent in the method are discussed.

CONCENTRATION OF MINOR AND TRACE ELEMENTS IN ASH OF LOW-RANK COALS FROM TEXAS, COLORADO, NORTH DAKOTA, AND SOUTH DAKOTA

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As part of the routine geochemical investigations of coal, 282 lignite samples from seven areas were analyzed spectrographically. C. L. Waring and C. S. Annell of the Geological Survey developed the method used for the semiquantitative estimation of 68 elements in one exposure of a 10-mg sample.

B, Ba, Sr, Pb, Ti, P, and Mn are present in concentrations as high as 0.1 to 1.0 per cent in most of the areas; As, V, Mo, Zr, Zn, Ni, Co, Be, and Y are present in similar concentrations in fewer areas. Cu, Cr, Sc, Ga, Ge, Li, and La are present in concentrations as high as 0.01 to 0.1 per cent; Yb is present as high as 0.001 to 0.01 per cent; and Ag was not found in concentrations higher than 0.001 per cent.

There are unusually high concentrations of Pb, Sn, Sr, Mo, Co, B, and La in many of the coal ashes analyzed. The trace-element content is given for ashed lignite from each of the seven areas.

COMPOSITIONAL CONTROL OF THE DIMENSIONAL PROPERTIES OF CRYSTALS

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The compositional control of crystal dimensions is illustrated by the Ca-containing amphiboles. The dimensions as expressed by the ratio of $\frac{\text{length in the } b \text{ direction}}{\text{length in the } c \text{ direction}}$ varies in the crystals measured from 0.09 for tremolite to 0.78 for Fe-rich hastingsite. These ratios are interpreted as being the crystallographic (or growth) expressions of the changes in bond forces as the composition changes from Al, Fe-poor tremolites to Al, Fe-rich hastingsites. Al, which substitutes for Si, weakens the Si-O bonds in the c direction and strengthens the Metal-O bonds in the directions of the a and b axes. Fe, which substitutes for Mg, and Al, which substitutes for Fe and Mg, further strengthen the bonds in the a and b directions and thus influence the development of the crystal in these directions.

The presence and development of the 010 face seems to be correlated with the substitution of Fe and/or Al for Mg.

Compositional control of crystal dimensions of other amphiboles and of pyroxenes is discussed. Implications of the dimensional ratios on grain size and the tendency to recrystallize are indicated.

CONICAL AND CYLINDRICAL STRUCTURES IN THE POTSDAM SANDSTONE, REDWOOD, NEW YORK

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Two cylindrical structures, one inverted conical structure, and seven structures having circular horizontal sections and vertical sections of unknown shapes occur in the upper Cambrian Potsdam sandstone 2 miles north of Redwood, New York. Their axes are approximately perpendicular to bedding planes of the Potsdam. The structures, composed of sandstone similar to that constituting the adjacent flat-lying strata, are delineated by buff and red laminations subparallel to their borders and by the abrupt termination of stratification of adjacent beds at their borders. The nearly circular sections range from 2 inches to 15 feet in diameter; at least two of the structures have axes greater than 9 feet long.

Similar structures in the Potsdam sandstone of this region have been interpreted previously to represent concretions, sediments deposited by whirlpools in potholes, and typical flat-lying Potsdam sandstone in which the original pigmentation was modified by geyser action or by the rising of springs through the unconsolidated Potsdam sand, the affected areas subsequently undergoing concretionary cementation.

Field relationships suggest that the structures at the Redwood locality were formed by movement of unconsolidated and/or partly consolidated sand into cavities developed in underlying sand by falling of that sand into cavities in the underlying Precambrian Grenville marble. Strikingly similar structures have been observed to form in sand—some with interstices filled with a liquid, giving larger units a higher degree of integrity—placed in a box and allowed to run through a hole in the bottom of the box.

DEEP-SEA CHANNELS

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Modern fathograms are tending to establish the common presence of riverlike channels traversing the deep sea floor. These channels have a low gradient, a shallow relief compared to submarine canyons, and are commonly leveed. It is suggested that they are formed by low-density turbidity currents. They are apparently of great importance in down-slope transportation of sediment and in forming "alluvial aprons" in the deep sea. At least some of these channels are extensions of submarine canyons incised in continental slopes.

Southwest of Ceylon, the Swedish Deep Sea Expedition crossed five trough-shaped and leveed depressions in an otherwise flat bottom which are probably striking examples of such channels. Three of these are more than a mile wide and 200–250 feet deep. (By comparison the Mississippi near New Orleans is half a mile wide and about 50 feet deep below its levees.) The sea floor of the Indian Ocean between India and Malaya appears to be a gently southward-sloping sedimentary plain. Foredeeps separate this plain from most of Malaya and Ceylon. Thus the Ganges submarine canyon appears as a possible source for some of these deep sea channels even though it is 1000 miles to the north.

SEISMIC REFRACTION MEASUREMENTS IN THE GULF OF MAINE

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Seismic refraction measurements were made in the Gulf of Maine in 1948 and 1952 as a continuation of the program of geophysical exploration of the continental margins. Sections from Portland,

Maine, to the northwest edge of Georges Banks, from Matinicus Rock, Maine, to Cultivator Shoal, and from Cape Ann, Mass., to Yarmouth, Nova Scotia, were observed.

Sediments of 5025 to 6800 ft/sec varied erratically in thickness from 0 to 2000 feet. To the north and east of Ammen Rock consolidated sediments of 12,000 to 13,000 ft/sec were detected with thicknesses up to 1600 feet. These are tentatively identified as Triassic and possibly represent a continuation of the Fundy Basin. Basement rocks with velocities of 16,500 to 18,000 ft/sec pinch out rapidly away from shore on all sections. Sub-basement rocks with velocities of 19,000 to 21,000 ft/sec underlie the entire Gulf of Maine.

NO CENOZOIC TEHUANTEPEC SEAWAYS

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Böse indicated in 1905 that no Cenozoic seaways crossed the Isthmus of Tehuantepec; nevertheless Mayr (1946) and Eardley (1951) have insisted on such a connection during later Tertiary time.

A re-examination of the Isthmus region clearly indicates that there have been no post-Cretaceous seaways across it, although Miocene seas from the north penetrated more than half way toward the Pacific. No post-Cretaceous marine sediments are present on the Pacific side of the continental divide nor are there any marine terraces on the extensive Tehuantepec plain, contrary to earlier statements. The Tehuantepec plain is separated from the bounding mountains in many places by faults. The adjacent continental shelf extends seaward about 50 miles, apparently as an extension of the plain. The break from the continental shelf to the continental slope occurs below 100 fathoms (200 m), thus suggesting a general late depression of the area which would explain the lack of marine terraces.

Thick gravels, of apparent Pleistocene age, representing several episodes of deposition, occur on the continental divide and northward from it. These gravels and interfingered clays suggest closed basin conditions and greater local relief or heavier rainfall.

Several sequences of apparent nonmarine rocks of presumed Tertiary age are present along the highway in the mountains northwest of Tehuantepec. In one of the younger sequences, near the village of Nejapa, a *Merychippus* palate and bones of a camelid, indicative of Miocene age, were found.

THERMAL, DEHYDRATION, AND X-RAY STUDIES ON MONTMORILLONITE

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The thermal reactions, water loss, and changes in crystal structure have been investigated between 500°C. and 950°C. for five montmorillonite samples with varying chemical composition.

The water loss during the first high-temperature endotherm accounts for the water proposed by the Hofmann-Endell-Wilm structure. This reaction involves changes in the spacings of the x-ray diffraction lines which probably reflect symmetry differences. There is some additional water loss which takes place slowly over the entire range between the first and second high-temperature endotherms with a gradual change in the spacings of the x-ray diffraction lines but no loss in the intensity of the pattern. Crystal water is essentially completely removed by the end of the second high-temperature endotherm. Water loss during this endotherm may well contribute to the thermal reaction but cannot fully account for it. During this endotherm the intensity of the x-ray powder pattern decreases rapidly indicating breakdown of the crystal structure and the formation of a disordered state which results in an increase in entropy. Thermodynamically the effect of increased entropy can be expressed by the general equation of third law, $dS = \frac{q}{T}$, where S is entropy; T, tem-

perature; and q heat absorbed. Thus q increases with S and manifests itself as an endothermal reaction accounting for the second high-temperature endotherm. The exothermic reaction which follows is attributed to the formation of spinel and partial return to an ordered state. Silica is not present as a crystalline phase in this temperature range.

PURIFICATION AND PROPERTIES OF MONTMORILLONITE

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With the use of thermal, x-ray, electron, and chemical methods, descriptive mineralogical data have been obtained on 10 montmorillonites from bentonite deposits in the United States and Canada.

The montmorillonites were hand-picked and subsequently mechanically purified by settling and supercentrifugation. After purification cristobalite was detected in 4 of the 10 samples. Lepidocroite and hydrous mica were present in one sample. The differential thermal-analysis curves show endothermic peaks at (140°–160°C.), (650°–715°C.), and (820°–885°C.) followed by an exothermic reaction above 870°C. X-ray powder photographs show basal spacings up to the tenth order yielding $d_{(00.1)}$: = 17.9 to 18.0A for glycerol-treated specimens. The electron micrographs reveal small, irregular thin plates. One sample showed some of the plates curled into tubes. The base-exchange capacity ranges from 66 to 128 milliequivalents per 100 grams of sample depending on impurities and chemical composition of the montmorillonite, but independent of particle size. Formulae calculated from the chemical analyses show a fairly wide range of isomorphism. The peak temperatures of the thermal reactions, the "a" and "b" dimensions of the unit cell, and base-exchange capacities are correlated with the substitution of magnesium and iron for aluminum in the octahedral layer and aluminum for silicon in the tetrahedral layer as determined from chemical analyses.

CORALS FROM THE REDWALL LIMESTONE (MISSISSIPPIAN) OF ARIZONA

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Stratigraphic distribution of the corals throughout the four members which make up the Redwall limestone includes six newly described species of cup, horn, and compound tetracorals collected from northern Arizona.

Correlation of the corals with those of the standard Mississippi Valley section suggests a lower Mississippian Kinderhook age for the entire Redwall studied from Pine to Seligman, Arizona. This is in agreement with the nautiloid cephalopods collected from the top of the formation at Jerome, Arizona; however, apparent discrepancies occur since some brachiopods, crinoids, blastoids, and other forms imply Osage and younger strata in the formation.

The study forms a basis for comparing the time equivalency of the formation with other prominent contemporaneous Mississippian carbonate units in western United States such as the Madison limestone throughout the Rocky Mountains, Monte Cristo formation of Nevada and California, and the Caballeros formation-Lake Valley limestone of New Mexico.

ORIGIN OF LISTWÄNITES OF THE CAUCASUS AND URALS

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Listwänites are widely distributed in eastern Europe and particularly in the Caucasus and Urals. At least three types have been observed: serpentinitic, gabbroic, and porphyritic. The author has investigated the serpentinitic listwänites.

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The term "serpentinitic listwänite" identifies a metamorphic rock composed chiefly of carbonates (ankerite, dolomite, breunnerite, magnesite, calcite) with varying quantities of quartz (from 25–30% to 70%) and accessories, such as antigorite, chlorite, magnetite, chromite, and others.

Contrary to the views of Karpinsky and Lodscohnikov, who considered them metamorphosed limestones, the serpentinitic listwänites are products of hydrothermal alterations of serpentinites. Listwänite occurs in the contact zones of the serpentinite bodies, and its formation and composition appear to be independent of the chemical composition of the country rock. These rocks are formed as a result of a replacement of the serpentinitic rocks by silicon-bearing carbonic hydrothermal solutions.

Commercial quantities of gold (on berezites) and of fluorite (on yougorites) are deposited during this replacement process. Listwänites were frequently used as ore indicators by gold prospectors.

The comparatively high content of CaO and SiO_2 on the listwänites is a good illustration of Larsen's polarity law.

VALUE OF MICROFOSSIL CENSUS STUDIES

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The patterns of census curves are as valuable for local and regional stratigraphic correlation as are electric and radioactive log patterns. Interpretation of these quantitative curves is the most reliable approach to environment studies. The kinds of microfossils counted and the extent of detail on the counting may be varied for each stratigraphic problem, but the method is best suited for non-indurated shale and sandy shale sections. Census studies are most adaptable to Mesozoic and Tertiary marine beds which contain abundant Foraminifera. The laborious time consuming counting process full of human error is the chief disadvantage of the method, and the counting problem remains unresolved.

TILLS OF THE FOUR GLACIAL STAGES IN EAST-CENTRAL ILLINOIS

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Exposures in valleys and in a strip mine in sections 1 and 2, T. 19 N., R. 12 W., 3 miles northwest of Danville, Illinois, show Nebraskan, Kansan, Illinoian, and Wisconsin tills and other glacial deposits. These drift sheets are differentiated by weathering profiles.

The exposed Nebraskan drift consists of thoroughly weathered till (gumbotil). The weathering is Aftonian. The gumbotil contains decomposed crystalline pebbles and Lafayette-type pebbles. It is overlain by Kansan drift consisting of proglacial silt and till. Yarmouth gumbotil is present at the top. The Illinoian drift consists of Loveland loess, proglacial outwash, and till, upon which Sangamon gumbotil is well developed. The overlying Wisconsin drift consists of loess, outwash, and till. The surficial material is Bloomington outwash (Tazewell).

These exposures are unusual because they show tills of all four glacial stages in one locality. The presence of Nebraskan till indicates a more extensive Nebraskan glaciation than has been known.

SILICIFIED TRILOBITE PROTASPIDS

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The early larval, or protaspid, stages of ontogeny are important in understanding relationships among trilobites. The following conclusions derive from incomplete studies of silicified protaspids of

more than 20 trilobite species etched from Middle Ordovician limestones from the Shenandoah Valley, Virginia.

1. As a trilobite is traced back through its ontogeny to the protaspid, first specific, and then generic characteristics fade. However, generic and even specific distinctions are determinable in some protaspids.

2. Many strikingly different types of protaspids occur: flat and disclike, moderately convex, nearly spherical. Marginal spines are characteristic in some.

3. Conspicuous changes in visible structures and considerable growth—as much as 250 per cent length increase—occur during protaspid period.

4. The most advanced protaspids of the species observed vary in length by a factor of four.

5. Minute hypostomes, vastly different from adult forms, are associated with many of the protaspids.

6. Some protaspids show the hypostome, rostrum, and free cheeks separated by sutures, others fused into a single plate which covers nearly the entire ventral side.

7. Protaspids of family Lichadidae show "normal" transverse glabellar segmentation. Typical lichadid lobation develops later.

8. Protaspids of family Odontopleuridae are proparian. Genal spines on fixed cheek later disappear, and adult is opistoparian.

9. A family characteristic of Encrinuridae protaspids is a spherical swelling lateral to axial furrow. In some species this forms part of fixed cheek in adult, in others it is incorporated into glabella.

RECENT RESULTS FROM EARTHQUAKE SURFACE-WAVE INVESTIGATIONS

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The dispersion and absorption of mantle Rayleigh waves with periods of 70–400 sec. have been investigated. The observed dispersion may be accounted for by the known increase of shear-wave velocity with depth in the mantle. A value of .000018 km^{-1} was deduced for the absorption coefficient of waves with periods of 230 sec. The internal friction in the upper mantle corresponding to this absorption is $\frac{1}{Q} = 590 \times 10^{-6}$, a value surprisingly similar to that reported from audio frequency-vibration studies on crystalline rocks at atmospheric pressure.

Investigation of the short-period surface-shear wave Lg, which propagates across continental paths with only a velocity of 3.51 km/sec. suggests that the large amplitudes and long duration of this phase can be accounted for only by wave-guide transmission through a remarkably homogeneous sialic plate which ends abruptly at the continental margins.

Investigation of Rayleigh waves traversing oceanic paths with periods from 16 to 40 sec. reveals that crustal structure beneath the Atlantic and Pacific oceans is characterized by the absence of any significant thickness of granitic rock and the occurrence of the Mohorovicic discontinuity at a depth of about 10 km below the sea surface.

STRATIGRAPHY AND PALEONTOLOGY OF THE LOGAN FORMATION IN CENTRAL AND SOUTHERN OHIO

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The stratigraphy and paleontology of the dominantly clastic Logan formation, the upper unit of the Lower Mississippian Waverly group of Ohio, have been studied from Licking County southward to the Ohio River.

The stratigraphy of the Logan in much of the area is revised. Two facies are recognized east to west: the Pretty Run (Holden, 1942), characterized by sandstone and pebble conglomerate, and a facies which is named, composed largely of siltstone and shale. A new member of the formation in the area of the siltstone and shale facies is defined.

Although the Logan is only sparsely fossiliferous, it has yielded a rather large fauna. The assemblage studied is classified as follows: Scyphozoa (2 species): *Paraconularia*, *"Conularia"*; Anthozoa (2 species): Neozaphrentid?, *Pleurodictyum* (*Procteria*); Annelida (1 species): *Cornulites;* Brachiopoda (34 species): *Lingula, Trigonoglossa, Orbiculoidea, Oehlertella, Rhipidomella, Leptaena, Schellwienella, Chonetes, Linoproductus, Dictyoclostus, Avonia, Camarotoechia, Pugnoides, Rhynchopora?, Cranaena?, Spiriferina, Spirifer, Syringothyris, Torynifer, Composita?, Eumetria?*; Pelecypoda (33 species): *Clinopistha?, Paleoneilo, Nucula, Nuculana, Cypricardella, Cypricardinia, Spathella?, Schizodus, Leptodesma, Oracardia, Pseudaviculopecten, Aviculopecten, Euchondria, Prothyris, Sanguinolites, Sphenotus?, Allorisma, Pholadella, Cardiomorpha, Edmondia, Conocardium*; Gastropoda (5 species): *Tropidodiscus, Euphemites, "Worthenia", Platyceras, Loxonema;* Trilobita (1 species): *Proetus.*

The dissimilarity of the Logan to faunas of equivalent age in the Mississippi Valley region renders impossible precise correlation of the formation with the standard Mississippian column. Stockdale's (1939) correlation of the Broadhead formation of Kentucky with the Logan is supported on the basis of paleontological evidence. The possibility that the Broadhead and consequently the Logan may be of upper Burlington and lower Keokuk age is discussed.

PROBABLE WISCONSIN SUBSTAGES AND LATE WISCONSIN EVENTS IN NORTHEASTERN UNITED STATES AND SOUTHEASTERN CANADA

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A variety of evidence suggests that the borders of the Cary and Mankato drift sheets cross eastern New York and New England, that there were two and perhaps three late Wisconsin marine invasions of the St. Lawrence lowland, and that there exist logical eastern correlatives of the low-water phases in the glacial upper Great Lakes, in the form of till-covered marine deposits, the abandoned, drift-filled Niagara gorge, and the North Bay—Ottawa River lake-outlet channel.

The evidence suggests further that the latest readvance of the ice-sheet margin in Manitoba, Ontario, and Quebec postdates the "postglacial" Thermal Maximum.

The suggested events from the Cary maximum to the present are assembled in a correlation chart for comparison and criticism. Although the scheme proposed is suggestive only, it is consistent with ecology implied by fossils, with the dates and amplitudes of known crustal movements, and with the radium and radiocarbon dates of all the dated materials collected from the region.

GEOLOGY OF THE EAST DELAWARE TUNNEL, NEW YORK

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This tunnel, part of New York city's water supply system, excavated from two portals and two intermediate shafts, will be 25½ miles in length and 11 feet 4 inches in diameter and is to be lined with concrete. Excavation is expected to be completed in November 1952. The formation penetrated, part of the Catskill series, consists of nearly flat-lying terrestrial sediments, red and gray shales, and graywacke sandstones, of Devonian age, carrying plant fossils. The formation contains interfingering lenses with much cross-bedding. Jointing is scarce. Only two decayed fault zones of any importance were encountered. Both brought in small amounts of methane and water, some of which was saline, but the largest water inflow was 165 gpm. The methane probably originated in one of the formations

underlying the Catskill series at depth. The shale members impede the downward percolation of meteoric water, so that the tunnel is comparatively dry. So-called "air-slacking" of the rock is attributed to the relief of stress, which, in the more massive sandstone beds, caused slight popping. Suspension type roof support, together with gunite, was used extensively, and proved very successful, particularly in the horizontally bedded rocks encountered.

The tunnel will deliver some 370 million gallons of water per day. The flow, with a drop in head of some 400 feet, will be used for generation of electric power as well as for water supply.

SIGNIFICANCE OF THE PLEISTOCENE IN THE GROUND-WATER RESOURCES OF ILLINOIS*

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Despite the fact that northern Illinois is underlain by very good deep-rock aquifers, the most productive water wells in the State tap the gravels of the Pleistocene. Studies by the Illinois State Geological Survey over a period of many years show that the most prolific sources of ground water are the preglacial valleys where they are buried with valley-train deposits of pre-Illinoian (Kansan?), Illinoian, and Wisconsin glaciations. Yields of 2500 to 3000 gallons per minute are common in the better glacial deposits—twice the yields of the deep Cambrian sandstones of northern Illinois.

The greatest deterrent to the full development of Pleistocene sources of ground water has been inability to predict their occurrence in advance of drilling. In areas of deep-rock aquifers, it is still common practice to develop the bedrock aquifers regardless of the type of Pleistocene deposits encountered. The uncertainty of the occurrence of the Pleistocene aquifers has often led to their discredit. The best encouragement toward the development of these unused resources comes from the complete integration of detailed glacial studies with preglacial bedrock surface mapping and with geophysical data. Studies of this type are a prime geological responsibility. For geographic reasons, Pleistocene gravels cannot in every case relieve the areas where withdrawal from deep aquifers is heavy. The Pleistocene gravel aquifers will be very significant where industry can move to these yet undeveloped sources of water.

RELATION BETWEEN IONIC SUBSTITUTION AND SWELLING IN MONTMORILLONITES

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The swelling of samples of Na-saturated montmorillonite from 12 localities was determined after separation of the clays from associated minerals. The degree of swelling, which ranged between 21 and 66 ml per gram of sample, showed no correlation with cation-exchange capacity or with tetrahedral charge; but it did show a correlation with octahedral substitution, in the direction of decrease in swelling with increase in octahedral substitution. Substituted Fe^{+2} has a greater depressing effect on swelling than Fe^{+3}, which in turn appears to have about the same depressing effect as Mg^{+2}.

Swelling, being an osmotic property of montmorillonite, is affected by degree of ionization. The more nearly complete the ionization, the greater the number of silicate sheets carrying a negative charge, the greater the tendency for the sheets to repel one another, and the greater the swelling; and vice versa. It is suggested that just as substitutions in acetic acid affect the strength and degree of ionization of the acid, so substitutions in the montmorillonite structure affect its degree of ionization and its swelling. The substitituon of the more electropositive Fe^{+3} and Mg^{+2} ions for Al^{+3} would

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tend to alter the surface energy of the montmorillonite structure with the result that, when the mineral is dispersed in water, the degree of ionization is less and the consequent swelling is less.

HYDROTHERMAL ALTERATION AFFECTS TUNNELING AND UNDERGROUND POWERHOUSE IN BRASIL

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Hydrothermal alteration is common to a large area of Archean gneisses in the western portion of the state of Rio de Janiero. Many zones of altered gneiss up to 125 feet in thickness have been encountered in diamond-drill holes, tunnels, and underground powerhouse excavation up to 1000 feet below the surface. This would not be expected by anyone not familiar with the area, since large masses of sound rock are also common. The zones of hydrothermally altered rock are normally covered by residual soils, and they cannot easily be recognized at the surface.

The feldspars of the gneisses in this area are always altered to kaolinite, but varying amounts of mica, quartz, hematite, limonite, and gibbsite are present. While the major faults and some of the larger joints have provided structures where the hydrothermal alteration is localized, the most widespread occurrences are without any definite sequence parallel to the foliations in the gneiss. The location and width of the zones are generally unpredictable without exploration by core drilling. The engineering problems in tunnels vary with the thickness and attitude of the zones and degree of alteration. Many of the zones required support in the larger tunnels, pressure shaft, and underground powerhouse, but seldom develop more than moderate pressure. Approximately 20 km. of tunnel for hydro-electric development and railroad has been driven in this portion of the state. Dikes and sills of syenite of probable Jurassic age are also hydrothermally altered, but dikes and sills of diabase of probable Triassic age are not altered. The diabase dikes interrupt the zones of hydrothermally altered rock and postdate the syenites.

PETROGRAPHIC EVIDENCE INDICATING POSSIBLE PATHS ALONG WHICH MATTER HAS MOVED IN AND AROUND QUARTZ AND FELDSPARS IN SOME METAMORPHIC ROCKS

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By appropriately adjusting the illumination in an ordinary petrographic microscope a considerable amount of detail, commonly overlooked, can be seen. Great relief differences can be produced enabling one to distinguish with ease quartz and K-feldspars by inspection in plain light. "Channels," outlined by a Becke line, occur in and around the edges of certain minerals. Zoisite, clinozoisite, sericite, and other minerals develop along the channels and in plagioclases where the channels leave quartz grains. The color of biotite has changed where the channels cross it, indicating compositional changes. The materials, added and subtracted, are thought to have moved along the channels.

No birefringence difference exists in quartz between the material in the channels (which has the lower index of refraction) and that on either side. This has tentatively been interpreted to mean that "chunks" of quartz (fragments of the lattice or particles of colloid size) have been removed and "porous" channel zones produced. A possible mechanism for this process is mentioned. H_2O molecules, H^+ or OH^- ions, now occupying these zones produce the lower index of refraction noted in the channels.

Photomicrographs illustrating these phenomena and laboratory experimental results are presented to support these conclusions.

PETROLOGY OF THE OLIVINE AMPHIBOLITE OF PARRY SOUND, ONTARIO, CANADA

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An island, approximately 260 by 150 feet, made up of olivine amphibolite is located in Blackstone Lake 15 miles southeast of Parry Sound. The rocks of the western part of the island show curvi-columnar structure.

The amphibolite consists of colorless amphibole, olivine, and serpentine with small amounts of colorless pyroxene, spinel, magnetite, and chlorite; chlorite is locally abundant. The colorless pyroxene, perhaps enstatite, forms coronas between olivine and the amphibole.

With the exception of olivine the minerals of the amphibolite are of secondary origin and have probably formed from olivine and pyroxene, while serpentine and chlorite also formed from amphibole. The chemical composition of the rock comes closest to that of a picrite.

Pegmatite dikes are abundant in the area, and diorite dikes cut the amphibolite. The formation of the olivine amphibolite from an original peridotite is probably due to metasomatic metamorphism caused by the dikes. Addition of Al and some Si is believed to have been responsible for the formation of amphibole from pyroxene; Mg, Fe, and Al ions in excess of those required for amphibole formation aided the formation of spinel. Near the dikes the rock is essentially a spinel amphibolite, and olivine is absent; the introduction of Si and Al appears to have converted the olivine into amphibole, the excess Mg and Fe going into spinel.

DEUTERIUM CONTENT OF NATURAL WATERS

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A mass spectrometric method for the accurate determination of the hydrogen deuterium ratio has been developed. It is possible to determine the ratio to $\pm 0.10\%$ using material of "normal abundance"—i.e., 1 part D in 6700 parts H. Samples as small as 0.1 mg. H_2 (0.001 ml. H_2O) can be run. Natural evaporation and condensation that have been shown to fractionate the oxygen isotopes also fractionate the hydrogen isotopes. The ratio of these two fractionation processes is equal to the ratio of the ratios of the H_2O/HDO and the H_2O^{16}/H_2O^{18} vapor pressures.

Ocean waters range from $+3.25$ to $+5.65$ mole % deuterium, while fresh waters of the U. S. range from -10.1 to $+4.3$ mole % deuterium, both relative to an arbitrary standard. An explanation of these variations based upon the measured fractionation coefficient between liquid water and vapor will be given.

STUDIES OF URANIUM MINERALS (XI): GUMMITE

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The name gummite has been applied in a generic sense to designate fine-grained, pseudomorphic alteration products of uraninite whose true identity is unknown. It is similar in usage to limonite and wad. Study of a suite of gummite pseudomorphs from 35 localities has shown that the true identity of the mineral phases present can be established in most instances by x-ray powder methods. The alteration of the parent uraninite is in general sequential: (1) oxidation of U^4 in large part to U^6 with preservation of the uraninite structure, color usually black, brownish black or greenish black; (2) complete oxidation to U^6 with the formation of new anhydrous or slightly hydrated oxide phases, chiefly clarkeite and "green uraninite", color brown to green; (3) formation of new, relatively highly hydrated oxide phases, chiefly fourmarierite and "Mineral X" of Palache and Berman (1933), rarely

schoepite, color yellow, orange or red; (4) formation of uranium silicates, chiefly uranophane and kasolite, less commonly beta-uranophane, rarely soddyite, color greenish yellow to straw yellow. The minerals of (2), (3), and (4) constitute gummite proper; mixtures are common. Clarkeite is a valid species, apparently one of the polymorphs of UO_3. "Tetragonal uraninite" and U_3O_8 were not observed in the course of the work.

STUDIES OF URANIUM MINERALS (XII): BILLIETITE AND BECQUERELITE

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Billietite ($BaO \cdot 6UO_3 \cdot 11H_2O$), originally described from Katanga by Vaes (1949), is a valid mineral species isostructural with becquerelite ("$2UO_3 \cdot 3H_2O$"). New chemical analyses and Weissenberg x-ray studies on two specimens of billietite from Katanga gave: (1) $a_0 = 12.04$Å, $b_0 = 14.25$, $c_0 = 15.06$; nX = 1.730, nY = 1.810, nZ = 1.815; BaO = 6.88, UO_3 = 82.76, H_2O = 8.97, SiO_2 = 0.76, CaO = 0.30, total = 99.76; S.G. = 5.57 (meas.), 5.33 (calc.); (2) $a_0 = 12.08$Å, $b_0 = 13.98$, $c_0 = 15.06$; nX = 1.725, nY = 1.780, nZ = 1.790; BaO = 7.41, UO_3 = 84.39, H_2O = 8.68, total = 100.48; S.G. = 5.15 (meas.), 5.40 (calc.). Billietite is orthorhombic, 2V (−) ~ 35°; X pale yellow, Y and Z deep golden yellow. There are $4(BaO \cdot 6UO_3 \cdot 11H_2O)$ per unit cell. The unit cell differs from that of Brasseur (1949) in that the a and b axes are interchanged and the b axis is doubled. Brassuer has $a_0 = 7.11$Å, $b_0 = 12.08$, $c_0 = 15.09$; nX = 1.730, nY = 1.822, nZ = 1.829; BaO = 6.95, UO_3 = 83.86, ign. loss = 10.49, total = 101.30.

A new analysis and x-ray study of becquerelite from Katanga gave: $a_0 = 12.45$Å, $b_0 = 13.92$, $c_0 = 15.09$; nX = 1.770, nY = 1.805, nZ = 1.820; UO_3 = 89.53, H_2O = 8.95, SiO_2 = 1.82, total = 100.30; S.G. = 5.3 (meas.), 5.56 (calc.). Becquerelite is orthorhombic, 2V (−) 30°; X yellow, Y and Z deep golden yellow. There are 14 ($2UO_3 \cdot 3H_2O$) in the unit cell.

The near coincidence in dimensions and intensities of the single crystal and powder photographs of billietite and becquerelite indicate that these minerals are isostructural. From the new analysis a formula ($7UO_3 \cdot 11H_2O$, with S.G. calc. = 5.60) for becquerelite can be written analogous to that of billietite. The unit cell contains four formula units. A substitution of one Ba for one U^6 is presumed. If the role of water in the structure were understood, it might be possible to explain the necessary valence compensation for such a substitution by the O to (OH) ratio in each mineral.

EXTENSION OF THE "DIFFERENCE PATTERSON" TO FACILITATE THE SOLUTION OF ORDER-DISORDER PROBLEMS

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Great difficulty is encountered in attempts to locate the specific metal positions from among the symmetrically distributed possible positions in those minerals based upon close-packed sulphur atoms (chalcopyrite, bornite, stannite, etc.). Because of the identity of many interatomic distance vectors the Patterson projections, or sections, of such structures cannot be readily solved, even by modern techniques.

If it can be shown, or assumed, that the nonsuperstructure X-ray reflections do not change in intensity when these structures are disordered then Patterson projections, or sections, made using the superstructure reflections alone represent vector maps where all vectors are suppressed except those between like atoms that change position during the disordering process. Positive peaks represent vectors between sites that have either both gained or both lost in atomic number through disordering. Negative peaks take on a significance; they represent vectors between two sites, one having gained and the other having lost in atomic number; hence they represent the vectors between unlike

atoms that change position during disordering. Chalcopyrite is used as a known example to show the advantages and shortcomings of the method. The method is being applied to the bornite problem.

URANIUM DEPOSITS IN THE BLACK HAWK DISTRICT, GRANT COUNTY, NEW MEXICO

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Pitchblende occurs in association with native silver and with nickel and cobalt arsenides and sulphides in the old Black Hawk district, 14 miles west of Silver City, New Mexico. The geologic setting is similar to that of the high-grade uranium deposits at Great Bear Lake, Canada, and at Joachimstahl, Czechoslovakia; and the mineralogical associations in the three localities are almost identical. In geologic setting and in mineralogical associations the Black Hawk deposits are unique in the United States. The Black Hawk district produced high-grade silver from 1881 to 1893, but the mines have been idle since that time and are at present inaccessible.

The ore is in fissure veins with a carbonate gangue in Precambrian quartz diorite gneiss. The veins trend north to northeast; and the deposits that contain radioactive minerals form a northeast-trending belt about 2 miles long. This belt parallels the elongation of a nearby monzonite porphyry stock. Most of the major deposits are along faults in the gneiss, adjacent to where the faults cut monzonite porphyry dikes or apophyses of the main stock. Diamond drilling to test the area for commercial deposits of uranium, nickel, and cobalt is in progress.

DETERMINATION OF RANK IN COAL BY DIFFERENTIAL-THERMAL ANALYSIS*

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Accurate determinations of the rank of coal ranging from lignite to meta-anthracite have been obtained using inexpensive conventional D.T.A. equipment commonly utilized in the study of clay. Sharp endothermic peaks indicating loss of volatile components exhibit sufficient variation for demarcation of rank. The use of vacuum or inert atmospheres is not required.

Results indicate the rank of coal depends on the structural organization of the coal as well as the amount and nature of volatile constituents. Boundaries between ranks are essentially in agreement with A.S.T.M. specifications. A complete gradational series was not observed. Breaks occurred between meta-anthracite and anthracite, medium-volatile bituminous and high-volatile bituminous, and at the boundary of subbituminous B coals.

The thermal curves can be correlated with Gieseler plasticity measurements and graphically indicate the region where physical changes occur with increasing temperature. Thermal curves of lower-rank coals change with time, caused by accelerated oxidation of the powdered sample. The change is gradual and progressive and introduces reproduction difficulties. Coals of medium volatile and higher rank change much more slowly and are reproducible.

MICROCLINE-SANIDINE STABILITY RELATIONS

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Natural potash feldspars crystallographically intermediate between microcline and sanidine are described. It is not yet known whether the intermediate states represent stable configurations of a disordering transition as a function of temperature, or whether they are nonequilibrium states.

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Conversion of microcline to monoclinic $KAlSi_3O_8$ can be induced by hydrothermal treatment, but the reverse (*i.e.*, "synthesis" of microcline) has not been accomplished and probably will not take place in times available for experimentation. X-ray patterns show that a small percentage of finely powdered microcline is converted when held several days at 550°C (8000 psi H_2O pressure). Conversion is apparently complete in this time at 800°C.

Hydrothermal treatment at 800°C of small microcline fragments used for single-crystal X-ray analysis shows the development of tiny oriented overgrowths of monoclinic feldspar on the microcline. This phenomenon, coupled with the fact that fine powder is converted to the monoclinic form relatively rapidly, whereas the small fragments (0.2 mm.) take very much longer, indicates that the conversion is brought about by surface recrystallization abetted by the hydrothermal environment. The fact that hydrothermal recrystallization to a monoclinic phase (that may be metastable at the temperature of crystallization) probably takes place in considerably less time than does stable internal readjustment in microcline makes experimental interpretation of the transition temperature or temperature range somewhat uncertain.

THEORETICAL CONSIDERATIONS IN GAMMA-RAY WELL LOGGING

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Gamma-ray logs are useful in determining subsurface stratigraphy in uncased and cased oil-field drill holes. Logs of diamond-drill holes may also be used to evaluate uranium reserves. A theoretical treatment of the problem indicates practical conclusions that have been overlooked in the usual empirical applications. Statistical fluctuations in the emission of gamma rays limit the resolution and logging speed. The use of scintillation counters affords some improvement. The theory allows corrections to be made for the increased apparent thickness of beds and the depth displacement caused by the finite length of the detector and the time constant of the circuitry. The effects of multiple strings of casing, eccentric location of detector, shielding around the detector, and radioactivity of mud and mud cake can be evaluated individually. The theory also is useful in evaluating the efficiency of radioactive tracers, the depth of penetration of radioactive bullets, and the radial weighting function in neutron-gamma logs. Limitations in the present treatment are: (1) a purely exponential and inverse square attenuation is assumed, (2) a uniform horizontal distribution of radioactive material in the formations is assumed, (3) the dip is assumed zero, and (4) the counting rate of the detector is assumed to be directly proportional to the gamma flux on the drill-hole axis.

CHEMICAL VARIATIONS IN THE PRE-TERTIARY ROCKS OF CORNUCOPIA, OREGON

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The Pre-Tertiary rocks of the Cornucopia area, in the southeastern part of the rugged Wallowa Mountains of northeastern Oregon, are chiefly metamorphosed sedimentary rocks of Paleozoic and Mesozoic age, and granitic rocks of varying composition. Hornfelses derived from argillaceous sedimentary rocks are dominantly of mesozonal grade.

The contacts of the granitic rocks with the metamorphic rocks are gradational. For example, a granitic mass 232 feet wide cut by a lower adit has transitional zones 30 and 38 feet respectively. Chemical variations across this zone include about 10 per cent increase in SiO_2 in the granitic rock with a corresponding decrease of nearly 5 per cent in $Fe_2O_3 + FeO$ and over 2 per cent MgO but with little change in CaO and Na_2O. Crystalloblastic textures prevail in the granitic rock as well as in the transitional zones.

From the 31 analyses afforded by a Geological Society of America grant, several variation diagrams have been made; these diagrams are quite different from those of magmatic rocks. The writer believes

the chemical variations can best be explained by the hypothesis of granitization rather than magmatic differentiation.

STABILITY OF MAGNESIAN CALCITES

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The geologic stability at earth-surface conditions of calcite solid solutions with at least 1 or 2 mole per cent $MgCO_3$ is suggested by the occurrence of such material in the Quaternary and Tertiary of Florida, and elsewhere.

However, it is also a commonly held view that the difference of size of Ca^{++} and Mg^{++} precludes the formation of stable magnesian calcites. In order to evaluate these matters, the stability of the hard parts of certain present-day algae and echinoids containing as much as 20 mole per cent $MgCO_3$ in solid solution has been studied. Ten-day runs at 300°C. in the presence of water expel little or none of the Mg, but similar runs at 400°C. produce a pure calcite and brucite. The presence of moderate CO_2 pressure appears to inhibit the breakdown of the solid solution.

Magnesian calcites containing at least 20 mole per cent $MgCO_3$ in solid solution have been produced synthetically both at room temperature and at elevated temperatures and pressures, but these products may be metastable. In the former case, in particular, the conditions under which crystal growth begins are critical; a high concentration of NaCl decreases the rate of growth and favors greater content of Mg in the carbonate solid solution.

MEASUREMENT OF THE PROPERTIES OF SEDIMENTS

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Single samples of aggregate materials may be uniquely defined by five measured properties—namely, composition of the constituents, their size, shape, orientation, and packing—*i.e.*, petrographically, by mineral composition, and by texture. This definition may be formally expressed as

$$P = f(m), f(s), f(sh), f(o), f(p) \quad (1)$$

where P is an index or characteristic which is some function of $[f(\,)]$ the five variables, composition (m), size (s), shape (sh), orientation (o) and packing (p).

The five variables may be dependent, independent, or interdependent; if directly dependent, specification of only one variable is necessary to define P uniquely. If completely independent each variable must be specified for each sample, and the index P becomes of little practical value. Experimental analysis indicates that the five variables are interdependent, and precise definition of P by quantitative measurement of the five variables becomes

$$P = f(m, s, sh, o, p) \quad (2)$$

In measuring grain-size distribution, for example, a sample is disaggregated and sieved; disaggregation implies removal of o and p, and the index becomes

$$P_{s_1} = f(m, s, sh) \quad (3)$$

No amount of ingenuity suffices to resolve these interacting variables. Grain size may also be measured as the long axis of quartz grains in thin section or

$$P_{s_2} = f(s, sh, o, p) \quad (4)$$

Attempts to correlate P_{s_1} and P_{s_2} can succeed only if all the variables are simultaneously and sepa-

rately evaluated, and this may be achieved only empirically. Finally size defined as the long axis of loose quartz grains mounted to show their maximum projection area yields

$$P_{s_3} = f(s, sh) \quad (5)$$

This appears to be the ultimate simplification because size without shape is meaningless, and by this procedure, only, may axes be uniquely and unequivocally defined.

SYNTHESES OF URANIUM MINERALS AT ROOM AND ELEVATED TEMPERATURES*

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Syntheses of uranium minerals are probably the best way of solving some of the problems accompanying the mineralogy of the several scores of natural uranium compounds. Uranyl minerals—that is, so-called secondary ones—were synthesized at room and elevated temperatures in solutions that usually had a terminal pH of 1 to 5. Zippeite ($5UO_3 \cdot 3SO_3 \cdot 10H_2O$) and becquerelite ($5UO_3 \cdot 10\text{-}12H_2O$) were made at room temperature. Fourmarierite ($3PbO \cdot 6UO_3 \cdot 5H_2O$) formed easily at 100°C. Curite ($3PbO \cdot 7UO_3 \cdot 4.5H_2O$), kasolite ($PbO \cdot UO_3 \cdot SiO_2 \cdot H_2O$), and soddyite ($5UO_3 \cdot 2SiO_3 \cdot 6H_2O$) readily formed at 180°C. and higher. The silica in kasolite and soddyite came from the glass containers of the experiments. Clarkeite ($UO_3 \cdot nH_2O$) is the only mineral recognized in solutions with a pH higher than 7 at 258°C. In many experiments one or two unknown compounds were found. Pitchblende (uraninite) was made at 50° to 212°C. by reduction of uranyl ions with H_2S or ferrous ions. Reactions below 50°C. are extremely slow. In some experiments at 212°C. hematite was a by-product of the pitchblende; this could explain the common hematitic staining in hydrothermal veins. Organic liquids can reduce uranyl ions to pitchblende at room temperature. Whether these organic reactions take place in the absence of light is not yet known. That they occur in ultraviolet radiation has been known for 50 years.

IRON DEPOSITS OF THE CONGONHAS DISTRICT, MINAS GERAIS, BRAZIL

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The Congonhas district, in the southwest corner of the iron region of central Minas Gerais, has been mapped by the U. S. Geological Survey in co-operation with the Brazilian Departmento Nacional da Produção Mineral. Large hematite deposits occur in the "Itabirite formation", the middle member of the Proterozoic (?) Minas series, a sequence of quartzites, schists, phyllites, ferruginous sediments, and carbonate rocks. Itabirite is a finely laminated rock composed essentially of quartz and iron oxides, chiefly hematite, that in places contains dolomite and amphibole. It is believed to represent metamorphosed chemical precipitates. Moderate deformation and uplift in post-Minas time preceded erosion and the deposition of quartzite and itabirite debris in conglomerates of the overlying Itacolumi series. Severe post-Itacolumi deformation folded and thrust faulted rocks of both series. Ultramafic intrusions antedate the orogeny; granodiorites and allied types are younger.

Local enrichment of the iron formation produced masses of high-grade ore (68–70 per cent Fe). Tight folds and breccia textures preserved in hard ore suggest that enrichment was post-deformation, but a moderate to strong cleavage, caused by orientation of the micaceous specularite, indicates that replacement preceded the close of the orogeny. Because many deposits occur at points of structural irregularity it is postulated that enrichment was contemporaneous with deformation and that severe stress may have played a part in localizing the deposits. As there is also evidence that some

* This investigation is a part of a contract with the Raw Materials Offices of the Atomic Energy Commission and is published with their permission.

hematite ores resulted from replacement of dolomite breccia, a combination of structural and mineralogic factors probably controlled their formation.

AGE RELATIONSHIPS OF CARBONIFEROUS FORMATIONS IN THE ROCKY MOUNTAINS OF CANADA*

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Stratigraphic and faunal studies of a thick series of Carboniferous rocks in the Canadian Rocky Mountains indicate that they are a continuation of similar rocks in the western United States, and extend northward to and beyond the Yukon-Alaska boundary. Three widespread lithological units have been recognized in the Alberta Rockies: the Banff, Rundle, and Rocky Mountain formations. Evidence of an erosional interval at the base of the Banff in some sections indicates slight emergence at the close of Devonian time. Two faunas occur in the Banff: the lower, with *Leptaena analoga* (Phillips), very widespread, occurs in the southern Rockies and also in the Yukon; it is mainly of Kinderhook age but contains younger elements. The upper fauna contains Osage, some Kinderhook, and a few anomalous post-Osage forms. The Banff-Rundle contact is believed to be diachronic. Correlation of the lower Rundle is uncertain, but the first appearance of lithostrotionids in the Upper Rundle is a good marker horizon; the uppermost beds contain some Chester elements. The lower Rocky Mountain formation is largely unfossiliferous; the few fossils suggest a Pennsylvanian age. A recent discovery of gastroceratids in the extreme south indicates beds of Oklan age. The upper part is mainly chert; it would correlate lithologically with the Phosphoria formation, but its Permian age has yet to be proved. The author's present research, begun in 1948, is continuing.

FURTHER IMPLICATIONS OF THE GEOMETRY OF GEOSYNCLINES

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Analyses are presented of hypothetical geometrical changes throughout a geosynclinal cycle based on these postulated limiting dimensions.

Stage 1. Incipient geosyncline with crustal layering of:
Sialic material 10 km.
Simatic material 25 km.
Ultra-simatic material below.

Stage 2. Full trough defined as the imaginary standard geosyncline on the width of 193 km. and depth of 18 km.

Stage 3. Primary compression with lateral shortening of 25 per cent.

Stage 4. Isostatic uplift and contemporaneous erosion ending with a stable shield and crustal layering of:
Sialic material 20 km.
Simatic material 15 km.

Possible trough-forming mechanisms of crustal buckling by compression, crustal sagging by loss of support, and crustal thinning by tensile extension are considered separately. True-scale cross sections of the theoretical forms are developed by imposing the movement dimensions on both the crust and fill while conserving the total cross-section areas. Comparison is made to crustal dimensions of the Alps and Sierra Nevada determined empirically by other workers.

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This geometric concept inevitably involves the origins of orthogeosynclinal troughs, granites, sheared metamorphics, folded and faulted sediments, and the steplike character of multiple erosion surfaces. Thus it is considered to imply the existence of integrated relationships obtainable by quantitative methods. A lateral variation of shearing strain with trough shape is given in illustration.

The contribution is a demonstration of how, with sufficient data, it will be possible to work back to the incipient conditions of an actual geosyncline explaining the actions which took place.

ILLUSTRATION OF TWO POSSIBLE PRINCIPLES USEFUL IN THE LOCATION OF REEF KNOLLS

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The Claytonville Oil Pool in Fisher County, Texas, is fairly typical of some Strawn reef knolls of the East Side Shelf of the Midland Basin. Discovery was predicted in 1949 on the basis of two principles which may prove applicable in other instances. (1) The elimination of regional dip facilitates the genetic interpretation of a random penetration. Two abandoned wells which topped the basal part of the reef mass at different datums were originally at nearly the same level. The configuration showed that either the crest had been accidentally bracketed or it lay on one side of a known strike line. Fortunately in both interpretations the position was the same.

(2) Thickness variations in a near reef limestone were postulated to be due to transporting energy derived from Strawn waves breaking around the knoll. Rationalizations from isopach data located energy foci which were assumed to have occupied similar positions near sea level. A prediction model constructed by extending reasonable slopes upward from these points to the crest has proved quite accurate in a lateral sense but was about 100 feet short of the full vertical development.

The actual and completely independent discovery in 1952 by other workers was based on improved knowledge gained from core tests and a series of successive failures. Maps are presented covering each facet of the problem and comparison with the reef as it is known today.

SUPERGLACIAL AND PROGLACIAL GEOLOGY OF THE MALASPINA GLACIER, ALASKA AND ITS BEARING ON GLACIAL FEATURES OF NEW ENGLAND*

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Three geologic zones can be distinguished at the stagnant margin of the Malaspina Glacier. The proglacial zone presents no evidence of ice beneath the glacial deposits of Wisconsin age. An intermediate zone has a thick covering of debris over an irregular, thin, wasting sheet of ice. The superglacial zone includes a relatively thin cover of glacial debris on a thick ice mass.

The proglacial zone is composed mostly of outwash deposited by streams emerging from the ice or from proglacial lakes. Ground moraine, lacustrine deposits, polygonal ridges of till, eskers, and kames are subordinate.

The intermediate zone is an area of active deposition, erosion, and change. Large areas of outwash are being kettled, leaving topography similar to kame terraces in form but dissimilar in origin; elsewhere eskers of superglacial origin are being produced by destruction of outwash.

The striking amount and variety of superglacial deposits on this modern glacier support the hypotheses of downwastage and stagnation proposed for glacial features in much of New England. Large superglacial stream systems, lakes, and associated morphologic forms related to the Malaspina Glacier suggest the origin of many forms of stratified drift in New England. Obviously, with such

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a continental ice sheet, superglacial features will come into existence and be destroyed many times in the seemingly chaotic lowering and reversal of topography during downwastage. But even when the ice sheet beneath the superglacial drift breaks up into blocks and finally disappears, the resulting forms will have had their origin in the superglacial deposits such as those now seen on the ice of the Malaspina Glacier.

GEOCHEMICAL PROSPECTING IN THE BLACKBIRD COBALT DISTRICT, IDAHO*

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During the 1951 field season, the U. S. Geological Survey conducted an experimental geochemical-prospecting study in the Blackbird cobalt district, Lemhi County, Idaho. The purpose was to determine whether the distribution of minor amounts of cobalt and copper in soil could be correlated with the distribution of cobaltite ore. More than 1800 samples of soil and stream sediment were collected and analyzed for cobalt and copper by rapid chemical methods developed by Hy Almond of the Geological Survey. The data of this investigation show that: (1) the mean cobalt content of soil outside the mineralized district is 20 ppm (parts per million); and (2) within an area of about 2 square miles enclosing almost all the known cobaltite occurrences of the district, the mean cobalt content of the soil is 100 ppm. The amount of cobalt within the anomalous area, in excess of that over unmineralized ground, is in the order of 1000 times the amount of cobalt in all the known deposits, when both amounts are expressed as tons per foot of depth. The cobalt content of soils over known cobalt ore ranges from 200 ppm to 1000 ppm. Trenching on the basis of geochemical data uncovered a zone strongly mineralized with cobaltite in a previously unexplored and unknown area. In some parts of the area studied, the variation in copper content parallels the variation in cobalt content; elsewhere the cobalt and copper patterns appear to be independent. The content of cobalt and copper in stream sediment closely reflects the content of those metals in the soils in the drainage basin upstream.

INTRUSIVE TUFF-BRECCIA

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Andesitic tuff-breccia of intrusive origin is widely exposed over an area of at least 100 square miles in northwest Wyoming in the east-central part of the Absaroka Range, a dissected volcanic plateau consisting mainly of Eocene deposits. The tuff-breccia occurs as one or more essentially horizontal sheets, an unusual feature for intrusive pyroclastic rock. The intrusive sheet(s) range in thickness from a maximum of about 650 feet to a minimum of 50 feet or less. Included blocks from the overlying beds, some as much as several hundred feet in diameter, are characteristic of the tuff-breccia. There is contact alteration of both these inclusions and the country rock.

Stratigraphic evidence suggests that the tuff-breccia was emplaced at relatively shallow depth (probably between 600 and 1900 feet); locally it probably reached the surface. The beds into which the pyroclastic rock was intruded were probably poorly consolidated and water-saturated. The occurrence of foreign material unlike near-by country rock and beds of the underlying sequence suggests underground lateral movement of several miles.

The temperature at the time of emplacement is unknown, although petrographic evidence suggests that the tuff-breccia did not contain liquid magma at the time of emplacement. Some heat (and volatiles) was probably required, however, for the contact alteration, characterized by chlorite (?) and hardening (silicification?).

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No satisfactory explanation can be given for the mode of origin and emplacement, but evidence suggests the relatively nonexplosive subcrustal formation of tuff-breccia and its injection under pressure.

ORIGIN OF CHERT IN THE HELDERBERG LIMESTONE OF WEST VIRGINIA

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The chert in the limestones of Helderberg age occurs both in nodules and in distinct beds. The margins of the chert masses are calcareous and in some places are bordered by a thin film of pyrite. Sponge spicules of the monactinellid and hexactinellid types are common. Most of the spicules in the chert are siliceous, but in the limestone they have been largely calcified. Several features indicate that the chert is of replacement origin. Structures in the chert are the same as in the adjacent limestone. Laminations in the limestone continue through rather than around the chert. Some chert shows distinct cross-bedding, yet there is no interfingering of the chert and limestone. In many places chert occurs on one side of a joint, and limestone on the other side. Beds rich in fossils which were originally calcareous are locally completely chertified. In oölitic limestones all gradations may be observed from normal calcareous oölites to siliceous oölites. Some of the silica for the chert may have been derived from the sponge spicules which were replaced by calcite in the enclosing limestone. This source does not appear to be adequate to account for all the silica where chert masses are abundant.

CHEMICAL DIFFERENTIATION OF MULTI-GENERATION PEGMATITE MINERALS

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Differentiated pegmatites, consisting of zones or combined zones and younger hydrothermal units, can contain more than one generation of a mineral species. Compositional variation of successive generations of a species is systematic and is a function of paragenetic position. Decreasing relative age of formation is accompanied, in plagioclase, by increasing Na_2O; in microcline by decreasing amounts of sodic plagioclase as exsolution perthite; and by increasing Rb_2O. Alkalies, except K_2O, also increase in lepidolite, tourmaline, beryl, and some phosphates, with younger generations of each. In garnet, tourmaline, columbite-tantalite, triphylite-lithiophilite, muscovite, and probably lepidolite the Fe:Mn ratio decreases with decreasing relative age. Likewise in columbite-tantalite Ta_2O_5 increases in younger members. Other multigeneration species that reveal compositional differences are amblygonite (in the F-OH ratio and in Na_2O), apatite (in the F-OH ratio and MnO), cassiterite, biotite, spodumene, quartz, and topaz. The small-scale, sequential changes in the composition of succeeding generations of pegmatite minerals reflect, in a general way, the large-scale variations in the magmatic differentiation series, gabbro to granite, and thus constitute an argument for the origin of structurally complex pegmatites through fractional crystallization.

METASOMATISM BY APOPHYSAL DIKES IN THE CRAWFORD NOTCH REGION, NEW HAMPSHIRE

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On the northwest side of Crawford Notch in the White Mountains of New Hampshire, a large ring-dike of Albany porphyritic quartz syenite fingers out into many apophysal dikes where it meets a body of fine-grained gneiss of the Littleton formation. The rock in the ring-dike proper is porphyritic quartz syenite which is composed of approximately equal amounts of euhedral phenocrysts of feld-

spar 1 cm. across, and of 0.5 mm. grained groundmass. The rock of the apophysal dikes ranges from quartz syenite porphyry to granite porphyry. The groundmass is dark gray to black, aphanitic, and composes two-thirds of the rock. The phenocrysts are similar to those in the porphyritic quartz syenite.

The apophysal dikes are enclosed in thick- to thin-bedded, fine-grained biotite gneiss and hornfels which are locally andalusite bearing. The dikes range from a few feet to 300 feet wide and from a few tens of feet to several hundred feet long. Most of the apophysal dikes are bordered by transitional zones ranging from a few inches to 25 feet wide which grade into fine-grained gneiss and hornfels. The most striking feature of the border zones is the occurrence in gneissic matrix of abundant feldspar "phenocrysts" like those of the dikes proper. The groundmass of the transitional zone is chiefly fine-grained gneissic material with abundant (added) tourmaline and intermixed constituents of the groundmass of the dikes.

It is concluded that significant amounts of rock-forming minerals as well as "mineralization products" such as tourmaline, sulfides, and silicification can be produced by metasomatic action of magmatic dikes even as fine-grained as porphyries.

NEW PLEISTOCENE INTERGLACIAL (SANGAMON?) LOCAL FAUNA FROM KANSAS AND ITS CLIMATIC SIGNIFICANCE

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The Jinglebob local fauna from Meade County, Kansas, was recovered from a slough deposit in the Kingsdown formation. The fauna is considered contemporaneous with the Cragin Quarry local fauna from Meade County and with the Rezabek local fauna from Lincoln County, Kansas. If there were only four major continental glaciations and three major interglacial intervals in North America, the fauna can be considered as having lived during part of the Sangamon interglacial. The fauna is known from 49 species of invertebrates, remains of fishes, amphibians, reptiles, birds, and mammals. The mammals are represented by the remains of 22 species. Assuming that the fossil mammals possessed nearly the same habitat preferences and tolerance as their nearest living relatives, the climatic conditions at the time the fossils lived in the High Plains region were more equable for plant and animal life than now. The presence of *Oryzomys*, the rice rat, and *Neofiber*, the round-tailed water rat, as well as other southeastern elements in the fauna, and the large association of invertebrates indicate marshy conditions along the stream valleys. The fauna indicates that the winters were much milder than now in that area, and as warm as or warmer than the winters along the coastal plain of Virginia, with summers cooler, not hot and dry. Annual rainfall of 35–40 inches is considered probable.

STRUCTURE AND METASOMATISM OF THE BELT SERIES NORTHWEST OF THE IDAHO BATHOLITH*

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The older rocks around the northwestern corner of the Idaho batholith belong to the Precambrian Belt series.

The area is structurally complex, situated at the junction of two arcuate segments of Nevadan folding and also on the western border of the Laramide orogenic belt. The major fold axis parallels the trend of the northern arcuate segment of Nevadan folding (N. 70°–80° W.). The lineation and axis of small folds parallel the trend of the southern arcuate segment (N. 50° E.). Both sets of folds are locally overturned to the south and are accompanied by low-angle thrusts. The gentle north-trending folds may be of Laramide age. The block faulting continued to Miocene time.

* Publication authorized by the Director, U. S. Geological Survey.

The main folding was accompanied by small intrusions of gabbro, diorite, and tonalite, intense metamorphism, and metasomatic introduction of hornblende, biotite, andesine, and accessories. Locally, a second period of metasomatism obliterated the folded structures and is interpreted as having caused the formation of monomineralic rocks like hornblendites and anorthosites. This second period of metasomatism may be contemporaneous with the emplacement of the quartz dioritic border zone of the batholith. Small intrusions of tonalite west of the batholith and the rocks of the quartz monozite series in the center and north of the batholith were emplaced after the second period of metasomatism.

Chemical analyses show that mainly silica was expelled, and Fe, Mg, Al, Ca, and Ti were introduced during the metasomatism.

MINIATURE PEDIMENTS NEAR CALISTOGA, CALIFORNIA

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In an area 50 feet by 100 feet at Franz Valley School, 4 miles west of Calistoga in the northern California Coast Ranges, two miniature steep-sided "mountain" residuals rise sharply about 4 feet above smooth rock-cut "pediment" surfaces which are veneered with silt, sand, and gravel. Both "mountains" and "pediments" are cut from homogeneous nonresistant tuff-breccia and resemble, on very small scale, the mountainous residuals and pediments of southwestern United States.

Neither the "pediment" surfaces nor rill channels which cross them are graded to local base levels nor is there evidence, except in one place, of undercutting by or lateral shifting of these rills. A provisional hypothesis is advanced: Slopes of the "mountain" fronts retreat by back-weathering due largely to raindrop impact and chemical attack by moss plants, while the "pediment" surfaces are stabilized and protected from further attack by moss plants by their thin mantle of sediments. Weathered debris is removed from the foot of the "mountain" slopes and moved gradually across the "pediment" surfaces by slopewash and raindrop splash which thus effectively control the slope of both the sediment mantle and the underlying "pediment" surfaces. Fortunately the area is small enough for the hypothesis to be tested experimentally. While several experiments are now being conducted, suggestions for additional experiments are hereby solicited.

TECTONIC AND STRATIGRAPHIC HISTORY OF THE ANCESTRAL ROCKIES OF COLORADO

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During early Paleozoic time, northeastern Colorado was part of the positive Transcontinental Arch; the remainder of Colorado was a shallow, shelf-type sea. A thin sequence of carbonate rocks was deposited over the State during Mississippian time. This deposition was followed by a period of erosion that developed a karst topography on the limestones.

In Pennsylvanian time, three elongate ranges of the ancestral Rockies—the Uncompahgre, Colorado, and Wet—were raised several thousand feet vertically. These ranges trend north to northwest, nearly at right angles to the trend of the stable Transcontinental Arch; the position of the early Paleozoic stable areas apparently had little effect in controlling their location. Peneplanation after the major Pennsylvanian uplift ended with an invasion of the Permian Phosphoria sea into the central Colorado basin as far south as Glenwood Springs. An overlap is shown along the western margin of the Uncompahgre Uplift, where Mississippian limestone beds stand at high angles and are overlapped by the gently dipping Cutler formation.

Subsequent minor uplifts in the Early Triassic resulted in the shedding of coarse arkosic sediments into adjacent basins. By Late Triassic time the sedimentation had changed until only siltstone was

deposited. In Jurassic time the crest was stable, and each successive formation overlapped the older until, in Early Cretaceous time, the Ancestral ranges were covered.

HYDROTHERMAL GEOCHEMISTRY OF MAGNETITE—PROGRESS REPORT

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Measurements in progress on the solubility of magnetite in water at temperatures to 500°C and 1000 bars show up to 0.0002 per cent Fe in solution. To avoid oxygen contamination, distilled water was boiled and swept with Seaford nitrogen. The water was either loaded into the open Morey bomb under a current of nitrogen, or introduced through the pressure-gauge capillary after evacuation and flushing with nitrogen. Upon completion of a run the solution was condensed from an opening in the pressure-gauge capillary, and immediately analyzed for Fe^{++} and Fe^{+++} with ortho-phenanthroline in a photoelectric colorimeter. By using long narrow cuvettes, and micro-quantities of concentrated solutions of purified reagents, the sensitivity was extended to 0.00005 per cent Fe with only 2 ml of sample.

Stainless steel bomb walls contaminate solutions with iron, which even penetrates sheet silver liners, necessitating bored liners of nonferrous alloy.

Investigations have begun on: (1) agitation to reduce the week's time now required for equilibrium, (2) analysis for H_2 in gas phase of the sample, (3) effect of pH on solubility, and (4) conversion of $Fe(OH)_2$ to magnetite under hydrothermal conditions.

POTASSIUM IN ULTRAMAFIC ROCKS

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Quantitative spectrochemical determinations of potassium in 49 ultramafic rocks of various types confirm earlier preliminary observations (L. H. Ahrens, W. H. Pinson, and M. M. Kearns, in press) that the abundance of potassium in these rocks is much less than has hitherto been thought. All dunites and serpentines contain about .001% K, which may be compared with Daly's average of .033% K in dunite. This earlier value and other published values of like magnitude are based on chemical determinations, usually by the Lawrence-Smith procedure. The presence of blank potassium in the $CaCO_3$ used in this method of analysis is probably the cause for the excessively high chemical value.

Dunite or material of similar chemical composition is sometimes considered to comprise a significant proportion of the earth's mantle: on the basis of the new abundance value, the heat contribution by potassium in such material is only about $\frac{1}{30}$ of that calculated from earlier abundance values. The heat contribution by potassium in dunite is probably a small fraction of that generated by the U + Th series; in chondritic material, however, heat production by potassium is about × 100 greater than in dunite and may be greater than that produced by U + Th series. Strictly quantitative comparisons may, however, not be made at this time because the U + Th abundance values for dunite and chondrite are not known accurately and are at present under revision.

GEOLOGIC SIGNIFICANCE OF IYATAYET ARCHAEOLOGICAL SITE, CAPE DENBIGH, ALASKA*

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A sequence of late Quaternary climatic fluctuations is recorded at Iyatayet, a stratified archaeological site at Cape Denbigh, Norton Bay, northwestern Alaska. Iyatayet is the discovery site of the Denbigh flint complex, the oldest well-known cultural horizon in Alaska.

* Publication authorized by the Director, U. S. Geological Survey

The site is on a 40-foot terrace at the mouth of Iyatayet Creek. Excavations reveal from bottom to top: (1) congeliturbate comprising most of the terrace; (2) the Denbigh culture layer; (3) sandy silt; (4) Eskimo midden. A Subarctic Brown Forest Soil profile extends from the surface into Eskimo midden. Similar, buried soils underlie Eskimo occupation levels and a peat layer interbedded with the sandy silt. A thin Podzol profile underlies the Denbigh layer.

The Denbigh layer is contorted in overturned folds formed by solifluction. The overlying Eskimo deposits are undisturbed.

The following chronology is indicated: (1) filling of Iyatayet valley with congeliturbate due to solifluction on adjoining slopes during late, cold substages of the Wisconsin; (2) stability and formation of Podzol during occupation by people of the Denbigh flint complex, probably during a brief warm interval about 8500 years ago, but possibly during a pre-Mankato interstadial; (3) renewed solifluction, which introduced silt into the valley bottom and folded the Denbigh layer, probably during a cold interval between 8500 and 4200 years ago, but possibly during the Mankato substage; (4) stability, formation of peat and associated Subarctic Brown Forest Soil, and dissection of the valley bottom during a warm interval ending about 3500 years ago; (5) intermittent occupation of Iyatayet valley by Eskimos during the past 2000 years.

POST-GLACIAL LOW-WATER STAGE OF LAKE MICHIGAN INDICATED BY BOTTOM SEDIMENTS

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Core samples taken from the deeper parts of Lake Michigan show a complete sequence of clay deposits from glacial to present time, whereas samples taken from depths less than 350 feet show that a part of this deep-water sequence is missing and is replaced by a shallow-water deposit of sand and shells. The sand and shells are overlain by normal deep-water clays. The shells are of species of gastropods and pelecypods whose living representatives inhabit water 1 to 15 feet deep.

The level of this low-water stage is placed at 350 feet below the present lake surface, and the time of the low-water stage is believed to be post-Algonquin and pre-Nipissing. This low-level Lake Michigan would have drained through the Straits of Mackinac into a low-level Lake Huron, which was proposed by G. M. Stanley in 1936.

HEAT PRODUCTION IN BASALTS AND THEIR ORIGIN

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Progress is being made on the measurement of the radioactivity of crustal rocks (including potassium) for the determination of heat generation. Present averages show 2.2×10^{-6} cal./gm.yr. for the basalts of the Columbia Plateau, Oregon, 1.0×10^{-6} for the intrusive diabase dikes of the Canadian Shield area, and 1.0×10^{-6} for the Deccan basalts of India.

The objective is a clearer definition of conditions limiting the origin of certain basic volcanic rocks, particularly those of a tholeiitic flood type, those associated with stable Shield areas, and those of an oceanic type. At present it appears that the thermal gradient in large, low-lying areas of old crystalline rocks, even allowing for a low average radioactivity to the depth of the Mohorovicic discontinuity, will not permit the temperatures needed for the production of basic magmas at depths less than 100 km under equilibrium conductive conditions, and at the same time the existence of a layer of material of basaltic composition at these depths for any great time is not permitted on the basis of its heat generation.

It therefore seems necessary to think in terms of at least local, transient, thermal columns caused by convected material in the mantle. If the convected material is of a peridotitic composition it would be necessary that a gravitational separation of a basaltlike extract be effected at some time

during the history of the column. This extract could not represent more than one part in 10^{-2} of the original mantle material.

RADIATION DAMAGE IN ZIRCON: A POSSIBLE AGE METHOD

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The relationship between crystal structure damage and total alpha particle irradiation in zircon has been studied. The total irradiation was based on estimated or measured age times alpha activity, and the damage was determined by the change of the X-ray diffraction angle from the (112) plane as measured to .01° by X-ray spectrometer. The angle was found to be 35.635° (2 θ) for completely undamaged material, and it approached 35.1° asymptotically as the zircon had suffered increasing dosages of alpha irradiation and become metamict. The difference between the measured angle and 35.635° was found to equal $0.535e^{-2.31\times10^{-16}\alpha}$ degrees, where α = total irradiation in alphas/mg. The results have been interpreted to indicate that 4.5×10^3 atoms are displaced per alpha disintegration and that the annealing rate is essentially zero at earth's surface temperature. The process appears to be usable for age measurement but generally limited to zircons of less than 500 alphas/mg./hr. activity.

It was further found that the zircon became "half-metamict" after a radioactive energy release of 685,000 cal./gm., indicating that only a fraction of a per cent of the energy is stored in the structure as disordered atoms, the remainder being lost as heat. Observations on the high annealing rate of common rock minerals show that the amount of energy capable of being stored in a rock by alpha damage is negligible in questions relating to petrogenesis and volcanism.

STATISTICAL STUDY OF TEXTURE OF ENCHANTED ROCK PLUTON, SOUTHWESTERN LLANO COUNTY, TEXAS

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Enchanted Rock pluton, one of Stenzel's Town Mountain series of plutons, covers 100 square miles, is of pear-shaped outline, and intruded into tightly folded Precambrian metamorphics.

Tectonic features within the mass and structural attitude of wall rocks indicate the northern third is phacolithic, but the remainder is probably discordant batholithic. The phacolithic part occupies a synclinal trough plunging 35–40° SE.

Density of the granite ranges from 2.62 to 2.66. Biotite-rich schlieren range from 2.93 to 3.02. Xenoliths run commonly 2.71–2.74 and may strike 15°–30° transverse to surrounding platy flow structure.

Seven traverses were run across the pluton, margin to center, normal to platy flow structure. Number and dimensions of microcline phenocrysts were recorded for a 100-square centimeter area at each station. Chi-square values were calculated for their long dimensional frequency. On horizontal cross section, crystals are rectangular. Brachypinacoids, basal pinacoids, macrodomes, and prisms predominate.

Variation diagrams showing number of crystals per 100 square centimeters and arithmetic mean of individual areas of these crystals have characteristic curves. Chi-square values show only probability that deviations from the hypothesis of independence are caused by chance.

Characteristic curves indicate textural changes and aid in determining cooling history and structure of the pluton. Judging from chi-square values, probability that curves obtained are due to chance is small. Chi-square values are especially significant when testing the long-dimensional frequencies of crystals from textural zones. Values are low when comparing crystals from the same zone; values are high for crystals from different zones.

OCCURRENCE OF OPTICALLY NEGATIVE FORSTERITE IN THE SYSTEM Na_2O-MgO-Al_2O_3-SiO_2

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Biaxial negative forsterite was crystallized from melts containing Na_2O, MgO, Al_2O_3, and SiO_2. The crystals show inclined extinction up to 10° and prominent embayments. Optic-axis interference figures indicate an optic angle lower than that reported in the literature for pure forsterite. X-ray diffraction patterns are identical with that reported in the literature for pure synthetic forsterite.

Although the ionic radii of both Na^+ and Al^{3+} differ radically from Mg^{2+}, the sum of the radii of Na^+ and $Al^{3+} = 2Mg^{2+}$. It is postulated that atomic substitution takes place on a limited scale to account for the change in optical properties and morphology of the crystals.

NEW APPROACH TO THE PROBLEM OF ESTIMATING TEMPERATURES IN THE EARTH'S CORE AND MANTLE

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Bullen and Ramsey have shown that the reciprocal of the compressibility κ is a linear function of the pressure p viz

$$1/\kappa = 1/\kappa_0 + ap \qquad (1)$$

This relationship holds both in the core and the mantle below 1000 km. In view of this result, it seems reasonable to suppose that a similar relationship exists between the reciprocal of the volume coefficient of thermal expansion α and the pressure p viz

$$1/\alpha = 1/\alpha_0 + bp \qquad (2)$$

Using Uffen's values of α within the mantle, it is found that they are in excellent agreement with hypothesis (2). This relation is assumed to hold both in the core and mantle, and an estimate is made of the adiabatic gradient throughout the Earth. The temperature at the boundary of the core is 4350°K and at the center of the Earth a little over 4800°K, the increase across the core being only 500°. The results have considerable interest and bearing on Bullard's theory of the transfer of heat from the core.

PRE-HURONIAN ("ARCHEAN") SEDIMENTARY AND VOLCANIC SEQUENCE IN NORTHERN MICHIGAN

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Areal mapping by the U. S. Geological Survey in Dickinson County, in the northern peninsula of Michigan, has disclosed a sequence of sedimentary and volcanic rocks of pre-Huronian ("Archean") age. Some sedimentary units of this sequence had previously been correlated with the lower Huronian Sturgeon quartzite. The pre-Huronian rocks, which rest unconformably on older granite, consist in ascending order of (1) conglomerate and arkose, with intercalated basic flows and acidic tuffs, (2) biotite-hornblende schists and graywacke, with a thin interbedded iron formation, and (3) basic volcanic rocks, now metamorphosed to amphibolite. The beds are nearly vertical and form a belt several miles wide and about 20 miles long. The upper units grade into a banded gneiss that borders a mass of later pre-Huronian granite, which is overlain unconformably by the basal strata of the

Huronian. The aggregate thickness of the pre-Huronian sedimentary and volcanic rocks is on the order of 10,000 feet.

So far as known, no pre-Huronian rocks of undoubted sedimentary origin from this region have previously been described. Of further interest is the presence of abundant pebbles and cobbles of vitreous quartzite in the conglomerate, which provides evidence for a still older sedimentary cycle.

U. S. GEOLOGICAL SURVEY'S FOREIGN TECHNICAL ASSISTANCE PROGRAM, 1940–1952*

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The U. S. Geological Survey has given technical assistance abroad continuously since 1940. The program began under the auspices of the State Department's "Inter Departmental Committee on Scientific and Cultural Cooperation with the American Republics" and was limited originally to Latin America. During the war years, funds were added from the Foreign Economic Administration. In 1943 Liberia and the Philippines were included, and in 1949, with the proclamation of Point IV and the organization of a State Department Technical Cooperation Administration, the program was extended to Asia, the Near East, and noncolonial Africa. Geological co-operation with the British Colonial Geological Survey, primarily in Africa, was made possible in 1950 under the auspices of and from funds provided by the Economic Cooperation Administration. During the past 12 years the Geological Survey, in co-operation with the corresponding national agency of the host country, has made geological investigations in Mexico, most Central American countries, Cuba, Haiti, Dominican Republic, Panama, Colombia, Venezuela, British Guiana, Brazil, Paraguay, Argentina, Uruguay, Chile, Bolivia, Ecuador, and Peru; in Italy, Greece, Iran, Iraq, Saudi Arabia, Afghanistan, India, Thailand, and the Philippine Republic; and in Libya, Liberia, Sierra Leone, Gold Coast, Nigeria, Uganda, Tanganyika, and Kenya. Approximately 140 of our geologists have participated at one time or another. Some investigations have been rapid reconnaissance for mineral deposits or for water supplies, as in Central America or Saudi Arabia. Some have been country-wide studies of mineral deposits, as in Colombia and Thailand; some have been detailed studies of important mineralized districts, as in Brazil and Mexico; and some have been studies in basic geological processes, such as the continuing observation of Paricutin Volcano. More than 150 reports have been published in English and many in the language of the country.

During these 12 years approximately 60 young geologists from foreign countries have spent periods up to 2 years as in-service trainees with the U. S. Geological Survey and have since returned to their countries. Several times this number have had training with our field parties abroad. Some scores of senior officers of foreign geological surveys and professors in foreign universities have been our guests for shorter periods and have visited field parties and American universities under our guidance.

The writer feels that the program has made substantial contributions to the resources of many countries and has done much to advance friendly relations among the geologists of the free world.

LOESS: ITS PETROGRAPHY, PHYSICAL BEHAVIOR, AND RELATIONSHIP TO ENGINEERING STRUCTURES

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If the term *loess* is to have engineering significance, its definition should exclude loesslike materials whose primary open fabric has been modified by erosion, transportation, and redeposition, or by consolidation in place. Loess is a quartzose, usually feldspathic sediment composed of silt, fine sand, and clay particles, arranged in an open fabric resulting in a natural dry density of about 85 pounds

* Publication authorized by the Director, U. S. Geological Survey

per cubic foot or less. The loess herein described is composed of glacio-fluvial materials, redeposited by wind.

Loess as a foundation or construction material exhibits the following properties: (1) variable compressive strength dependent upon moisture content; (2) abnormal shear and consolidation characteristics; (3) high vertical permeability; (4) low unit weight; and (5) peculiar compaction characteristics.

The following examples illustrate recent engineering problems and experience involving loess:

Trenton Dam. The right abutment overlies deep loess. The loess was preirrigated to minimize consolidation after loading. The embankment impervious zone is recompacted loess.

Johnson Canal. Much of the canal is in loess with some almost vertical cuts exceeding 90 feet. Some seepage and slides have occurred.

Radio Relay Towers. These towers have high bearing pressures and are supported with or without piling by loess and loesslike materials.

Piling. Research was conducted near Ashton, Nebraska, on driven and jetted, steel and timber piles. Bridge piling at Trenton Dam exhibited lateral movement after placement of adjacent loess fill.

Miscellaneous. Loess road cuts have been easily maintained with almost vertical walls. Research is being conducted on the fusing of loess to make ballast and riprap.

MULTIPLE GLACIATION OF THE UPPER COOK INLET AREA, SOUTH-CENTRAL ALASKA

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Glacier-scoured surfaces, moraines, and marginal channels in mountain areas and moraines in lowlands bordering Cook Inlet permit consideration of four Quaternary glaciations. Glaciers fed from marginal ice caps entered the Cook Inlet trough from the west, north, and east. Evidence for successively younger episodes is preserved lower on mountain slopes and on lowlands closer to mountain fronts.

The oldest glaciation is inferred from broad summit surfaces above the limits of subsequent glaciation. On the basis of these surfaces Capps postulated that ice filled the trough to altitudes above 4000 feet. The next glaciation, recorded by extensively modified moraines preserved locally below summit-surface remnants and above deposits of the succeeding episode, filled the trough with ice to altitudes of 3000 to 3500 feet. The third recognized glaciation is recorded by little-dissected lateral moraines at altitudes of 1000 to 2000 feet along the mountain fronts and in major mountain valleys. Some mountain areas, previously glaciated, were ice free. Distinct differences in modification of glacial-valley form in the mountains suggest a major break between the second and third glaciation. The last recognized glaciation did not fill the trough. Piedmont glaciers deposited end moraines at the mouth of Matanuska Valley and as much as 15 miles out from the Alaska Range and Kenai Mountain fronts.

The last glaciation (Mankato?) advanced between 14,000 and 5,000 years ago; the previous glaciation (Cary or earlier Wisconsin?) more than 19,000 years ago (radiocarbon dating). The oldest two may be early Wisconsin or pre-Wisconsin.

LATE PALEOZOIC OROGENY IN CENTRAL NEVADA

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Several stages of late Paleozoic orogeny have been recognized in central Nevada. A belt between the Humboldt River near Carlin and the Toquima Range near Belmont has two stratigraphic sequences. One has Ordovician graptolitic argillite, graywacke, chert, and volcanic rocks that were

folded and bevelled before overlap of Carboniferous sediments. The other has thousands of feet of Ordovician, Silurian, and Devonian, principally carbonate rocks. In a 20-mile wide belt, the former sequence has been faulted down into the latter along normal faults. The Ordovician argillaceous sequence previously had been thrust eastward over the carbonate-rock sequence, as reported in the Roberts Mountains by Merriam and Anderson. The argillites are unconformable below Pennsylvanian carbonatite and conglomerate in the Toquima Range along Mill Creek canyon; at Tyrone Gap in the Sulphur Springs Range north of Eureka, cherts and argillites underlie a thousand feet of Wolfcampian carbonatite and quartz siltstone, lying below half a mile of chert pebble-bearing conglomerate. At Tonka Gap on Humboldt River, similar carbonatite and succeeding quartz arenite unconformably bevels earlier Pennsylvanian conglomerate and fossiliferous calcareous interbeds. The principal folding and thrusting seems to have preceded Pennsylvanian deposition; further folding preceded Wolfcampian. All the rocks were tilted and normal faulted by later disturbances.

RATIO OF OXYGEN ISOTOPES IN QUARTZ OF CONTRASTED ORIGIN

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Measurements of the O^{18}:O^{16} ratio in carbon dioxide produced by reaction of quartz with carbon in a vacuum furnace show that samples of quartz from a geological environment indicative of relatively low temperature of quartz growth have a higher content of O^{18} than do quartz samples formed at higher temperature. Differences are small but readily measureable with the mass spectrometer. Results indicate that the oxygen isotope ratio of quartz, taken in conjunction with other data, including data on the high-low inversion, may provide a useful clue to geologic temperatures in a relatively low range.

ALTERATION AND URANIUM MINERALIZATION, MARYSVALE, UTAH

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Alteration zones containing a sequence of clay minerals, silicification, alunitization, or pyritization occur in a variety of rock types in an area of about 50 square miles at Marysvale, Utah. Two field seasons with intervening laboratory study have been devoted to an analysis of the relationship between the alteration and uranium mineralization. More significant channels of alteration have been mapped.

The area has been mapped to establish correlation between the alteration and rock types. The major geologic units, such as the Bullion Canyon volcanic series, the Mount Belknap volcanics, and the intrusives have been subdivided for greater clarity in structural interpretation, interpretation of the alteration, and the delineation of host rocks presumably favorable to the deposition of uranium.

Alteration appears to diminish in the Mount Belknap red facies. Minor bleached areas occur along faults and shear zones. These are characterized by the development of adularia but contain few clay minerals. Such zones traced into bordering rocks of the Bullion Canyon volcanic series or intrusives may show enlargement and the development of argillic alteration.

Uranium-bearing veins contain both oxidized uranium minerals and uraninite. Fluorite is a common associate becoming darker near ore zones. Jordisite and ilsemannite are associated vein minerals. Montmorillonite, hydromica, and kaolinite are common clay mineral constituents of the uranium vein walls. Localized hematitic alteration may be observed. Biotite may develop as an alteration mineral. Brecciated thin quartz veins, pyritic and chloritic zones, and occasionally magnetite zones occur in the uraninite area.

Uranium minerals have been found in several units of the Bullion Canyon series accompanied by

zones of argillic alteration. The principal veins found, however, are in quartz monzonite or fine-grained granite. The Mount Belknap has not yet yielded more than migratory secondary mineralization along fractures. Alunitic zones are generally free from uranium, but uranium mineralization is occasionally found near by.

Conclusions presented constitute a progress report on the Marysvale Alteration Study jointly sponsored by the Division of Raw Materials, Atomic Energy Commission, and the Department of Geology, Columbia University.

FORAMINIFERA OF A DEEP-SEA CORE FROM THE ROSS SEA, ANTARCTICA

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During the 1946–1947 U. S. Navy Antarctic Expedition (HIJUMP) three ocean-bottom cores were collected by J. L. Hough in the pack-ice area of the Ross Sea. This report summarizes the detailed study of the Foraminifera from one of these cores, N-5, taken at a depth of 2991 meters with a recovered length of 242 centimeters. The foraminiferal zone is restricted to the upper third of the core and is essentially a zone of globigerina ooze. Of the 31 species identified from this zone, 5 are arenaceous, and the remainder hyaline. The arenaceous species constitute less than 1 per cent of the individual tests present. Among the hyaline forms several are dwarfed species. Two of the 31 species are pelagic and occur in very large numbers in the middle part of the Foraminifera zone where they constitute the major part of the foraminiferal fauna. The 29 benthonic Foraminifera of N-5 represent a typical deep and cold water benthonic fauna.

Of the other two cores collected in the area, one core has Foraminifera throughout its length, whereas the other is void of foraminiferal tests. It is postulated that the unlike vertical distribution of fauna in the three cores bears a direct relationship to changes in sea level in the Ross Sea area during and since the Pleistocene. J. L. Hough and W. D. Urry have dated these three cores as Pleistocene.

MICROPALEONTOLOGY AND GEOLOGY OF THE GAY HEAD CLIFFS, MASSACHUSETTS

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The Gay Head Cliffs on Marthas Vineyard, Massachusetts, offer the best exposures of the extreme northern Atlantic Coastal Plain sediments. Recent investigations necessitate revision of the complex geology of this famous locality.

The lowest beds here exposed have been considered Upper Cretaceous on the basis of plant fossils. However, the lignite clays at the bottom of the formation contain a unique pollen flora of possible Lower Cretaceous age.

A disrupted conglomerate occurs above the Cretaceous at the base of fossiliferous Miocene greensands. In places, where these sands are absent, a similar conglomerate occurs at the base of the Pleistocene. Tertiary and Pleistocene vertebrate fossils show the latter conglomerate to be a Pleistocene deposit derived from the erosion of the Tertiary beds.

A blue clay resting unconformably on the Miocene contains a dry-cold climate pollen flora of northern scrub pine and spruce, indicating a Pleistocene age for this and the overlying sand. At one locality this sand contains abundant *Venus mercenaria* and some Foraminifera.

Above the sand are glacial till and gravel. On these lie marine clays and silts containing pollen common to similar interglacial clays in southeastern Massachusetts.

At the top of the section are Wisconsin glacial deposits, eolian sand, and postglacial peat previously considered to be interglacial.

RELATION OF LAND LIFE IN EASTERN ASIA TO THE AKIYOSHI AND SAKAWA CYCLES OF OROGENY

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Land life is more intimately related to the orogenic cycle than is marine life. Estherians, molluscans, and other land animals and plants developed greatly in Eastern Asia after they declined in Europe. The shifting of the orogenic cycle from the Caledonio-Variscan on the west side to the Permo-Triassic Akiyoshi and Jurasso-Cretaceous Sakawa cycle on the east side of Eurasia must be the principal reason for this, because great changes in paleogeography and paleoclimatology have been brought about by these cycles.

The relations of various groups of plants and animals to physical factors of their environments are, however, complicated. An aberrant molluscan group was, for example, introduced in the Sakawa cycle as a relic fauna in a land-locked basin. Estherians experienced phyletic rejuvenescence in Eastern Asia in the Mesozoic era. Their faunal aspect in the pericontinental basins in the orogenic period was quite different from the interorogenic inland basins.

Climatic control of land plants is clearly represented in the floral composition of different ages and areas; of particular significance was the distribution of the Dipteridaceae and other important elements. The Mesozoic climate of Japan as indicated by land plants and other biota was warm, and at one time even tropical.

A tentative classification of nonmarine Mesozoic formations on the continent is shown; brief mention is made of Mesozoic vertebrates.

MULTIPLE GLACIATION IN THE SOUTHWESTERN KENAI PENINSULA, ALASKA

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Lowland moraines, and glacial deposits on the higher piedmont summits indicate that the southwestern Kenai Peninsula was glaciated at least three times during the Quaternary. During the earliest recognized glaciation, glaciers from the Alaska Range to the west, Talkeetna Range to the north, and Kenai Mountains to the east and southeast coalesced in the Cook Inlet trough. Later glaciations were successively less extensive.

The earliest recognized glaciation covered the southwestern Kenai piedmont, and deposited till containing granite erratics derived from the north and east. This material is exposed locally in cut banks of the Anchor River, where it underlies till of the subsequent glaciation.

During the second recognized glaciation, the southwestern Kenai piedmont was probably covered. Marginal channels at 2000 feet, just below the highest summit areas, suggest a stillstand during the recession. Initial depressions in the moraine are filled with peat and sandy silt; drainage is well integrated.

During the last recognized glaciation, ice from the Kenai Mountains spread around the eastern flanks of the piedmont to an altitude of 1600 feet, and filled the troughs of Tustumena Lake and Kachemak Bay. End moraines of this glaciation contain numerous small kettle lakes.

At least three readvances or stillstands during the last major deglaciation are recorded by concentric morainal loops in the Tustumena trough. More recent glacial fluctuations in the Kenai Mountains are indicated by two moraines within a mile of the present glacier fronts.

The three major glaciations are considered equivalent to the last three glacial episodes recognized by T. N. V. Karlstrom in the upper Cook Inlet area.

CARBON 14 MEASUREMENTS ON GEOLOGICAL SAMPLES

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Carbon 14 age measurements on various types of geological samples which have been made during the last year are reported. Wood specimens from cores taken in the Mississippi delta region show that the last major sea-level lowering (on the order of 400 feet) occurred more than 30,000 years ago and that the rise has been more or less continuous since then. The time of a certain sea level in the Mississippi delta region is very close to the same level on Bermuda. A survey of the carbon 14 content of the atmosphere indicates that it is essentially constant and corresponds closely to that for living wood. The carbon 14 concentration in ocean carbonate is much less for deep water than for surface water, suggesting that the rate of ocean turnover is of the order of thousands of years. There is evidence for a variation in the carbon 14 concentration of the surface ocean water. This is important in the evaluation of ages derived from shell material.

FOUNDATION OF ENIWETOK ATOLL*

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Drilling on Eniwetok Atoll, Marshall Islands, revealed the presence of olivine basalt beneath shallow-water Eocene limestone at a depth of 4170 feet.

Two holes were put down on opposite sides of the atoll: No. 1 on the northwest where a guyot adjoins the atoll at 700 fathoms, and No. 2 on the southeast where no guyot is present. In hole No. 1 hard basement rock was struck at 4610 feet, but no sample was recovered. In hole No. 2 fresh basalt cuttings were obtained at 4170 feet, and solid core from 4208 to 4222 feet.

Each hole penetrated several hundred feet of soft, Quaternary reef limestone before entering a thick Tertiary section. The Tertiary sediments are mostly limestones with minor amounts of dolomite, dolomitic limestone, carbonaceous clay, and silt. Most of the section is soft or weakly consolidated. The two holes are similar to depths of 1400 feet; below this point there are striking differences in lithology, organic constitution, and the distribution of hard rock and cavities.

INFLUENCE OF SEISMOLOGICAL FACTORS ON FOUNDATION DESIGN

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The pattern of motion resulting from the passage of earth waves of different types influences the effects of these waves on structures. Terrane governs the local effects of all types of waves.

Empirical criteria for the threshold of damage from earth waves show it to be an unexpected function of frequency. The threshold may be near .1 *g* at a frequency of 2 cps, but *g* at 20 cps. An acceleration of the order of .5 *g* seems to be required to cause landslides in weak pyroclastics or loess.

Earthquakes of sufficient magnitude to damage sound structures within a radius of 20 to 50 miles are not common.

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PETROGENESIS OF A GABBRO-GRANOPHYRE COMPLEX IN NORTHERN WISCONSIN

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A gabbro-granophyre complex is exposed in northern Wisconsin on the steeply dipping south limb of the Lake Superior geosyncline. The complex consists of two distinct belts of middle Keweenawan gabbro and granophyre split by a narrow belt of lower Keweenawan extrusives. Younger basic dikes cut the area.

The gabbro was intruded along zones of weakness developed between certain flow units during the formation of the geosyncline. In the gabbro two apparently unrelated structures are found. The first, fluxion structure, is believed to be due to shear or flow as the mass crystallized. The second, rhythmic layering, appears to be related to crystal settling. Gabbroic mineral compositions reveal simultaneous soda enrichment in plagioclase and iron enrichment in coexisting pyroxenes and olivines.

Between the gabbro and granophyre a narrow zone of "intermediate rock" exhibits peculiar mineralogical and textural characters. Fourteen features of this zone indicate that it originated as an alteration product of gabbro through contact action of a granophyric melt. For the granophyre, criteria of a replacement origin are inconclusive. Eleven facts strongly support a magmatic origin. The granitic magma may have developed through partial refusion in the lower reaches of the geosyncline or through fractional crystallization at depth. The resulting granophyric texture is unrelated to eutectic crystallization.

As a result of the contact action of granophyre magma on solidified gabbro, geochemical culminations of TiO_2, FeO, MnO, and P_2O_5 occur in the "intermediate zone". Variations in isotopic compositions of oxygen also resulted from this contact metasomatism.

APPLICATION OF CHEMICAL GRADIENT TO STRATIGRAPHIC CORRELATION

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The Jeffersonville limestone (Devonian, Onondagan) crops out in southern Indiana along a north-south distance of about 75 miles. Throughout this distance and in cores from the subsurface the formation can be divided into three zones on the bases of lithology and general faunal character. An increase in dolomite content of each zone northward along the outcrop has been noted in the field. Spectrographic determinations of major constituents of chip samples have been made and the results plotted versus sample locations projected on a north-south line. In all, 17 localities that contained one or more of the zones were sampled. The increase in magnesium carbonate and the decrease in calcium carbonate northward proved rather regular for six outcrops and one core (from 66 miles downdip to the west) that contain the entire formation; other constituents have rather uniform distribution. Less regular but distinctive magnesium carbonate-calcium carbonate gradients were found for each individual zone. Other constituents were more erratic, but less so than expected for the distance involved. The plots have proved useful in identification of the individual zones represented by samples from outcrops at which only a portion of the formation is exposed. Applied to the Jeffersonville and most other limestone formations in Indiana, the plots are useful in prediction of analyses of lithologic units at points between sample locations.

RELATION OF PITCHBLENDE DEPOSITS TO HYPOGENE ZONING IN THE FRONT RANGE MINERAL BELT, COLORADO

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The distribution of pitchblende deposits in several Front Range mining districts shows a distinctive relation to the pattern of hypogene zoning. The deposits appear to be restricted to an inter-

mediate or transitional zone between central areas of pyritic gold veins and peripheral areas of silver-lead-zinc veins. At present we do not know whether pitchblende is more common in the inner or the outer part of the intermediate zone. In at least one district (Central City) significant quantities of copper in the form of chalcopyrite have been produced from the intermediate zone. The position of uranium in an intermediate zone between gold and zinc was tentatively implied by W. H. Emmons (1926) in his generalized treatment of hypogene zoning.

At least seven local geologic factors must be considered in interpreting the zonal distribution of Front Range pitchblende deposits: bostonite intrusives, fault patterns, multiple stages of uranium mineralization, differences between paragenetic sequence and position of minerals in successive zones, correlation of pitchblende with copper sulfides (and sulfosalts?), scale and complexity of zoning in plan and in section, and effective depth of mineralization. The significance of some of these factors can already be evaluated.

The concept of the position of pitchblende in hypogene zoning is developed to stimulate and guide the systematic search for pitchblende deposits. Though the zonal position of pitchblende deposits is best known for areas of complex base-metal mineralization dominantly of mesothermal (possibly xenothermal) character, knowledge of the zonal position of uranium deposits in widely different geologic environments might be similarly useful in a search for ore.

RELATIONSHIP BETWEEN POLYMORPHISM AND COMPOSITION IN THE MUSCOVITE-LEPIDOLITE SERIES

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A determination of the crystal structures of 500 muscovites and lepidolites, approximately 50 of which are of known composition, has demonstrated the existence of a complete series between muscovite and lepidolite. The polymorphic variation in this series can be correlated with chemical composition, particularly with Li_2O content. A new variant of the muscovite structure has been discovered for which the term lithian muscovite is proposed. This modification crystallizes with a structure very similar to that of normal muscovite and apparently links heptaphyllite muscovite with octophyllite lepidolite. Micas with 3.2–4.0% Li_2O are generally characterized by poor crystal development and anomalous optical properties owing to their transitional structures. Lepidolites with 4.0–5.1% Li_2O generally crystallize as the 6-layer monoclinic polymorph, whereas those with more than 5.1% Li_2O have usually crystallized as the 1-layer monoclinic polymorph. Rhombohedral lepidolite is commonly associated with the 1-layer monoclinic polymorph, and both have essentially identical compositions. Twinning may be responsible for the rhombohedral form. Polymorphic modifications of lepidolite may occur across sheets and also along the *c* axis directions in single books.

MINERALS OF THE SAPUCAIA PEGMATITE MINE: FAHEYITE, A NEW BERYLLIUM PHOSPHATE*

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Faheyite, a new mineral from the Sapucaia pegmatite mine, Minas Gerais, Brazil, has the composition (Mn, Mg, Na)$Be_2Fe_2(PO_4)_4 \cdot 6H_2O$. It occurs as white, bluish-white, or brownish-white minute fibers that coat minerals in vugs. Evidences for a late-stage phosphate mineralization include the occurrence of faheyite as tufts of fibers on altered muscovite, as flat rosettes between muscovite sheets, and as fiber coating on euhedral crystals of quartz and variscite. The variscite crystals are unusual in that they are raspberry red and contain up to 2.46 per cent MnO. Crystals of roscherite, childrenite, amblygonite, and apatite and botryoidal masses of frondelite also occur in the vugs.

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The powder pattern has been completely indexed on the basis of a primitive hexagonal cell with dimensions $a_0 = 9.43$ Å, $c_0 = 16.00$ Å; the cell contents are $Z = 3$. The powder film was compared with a rotation picture of a fiber taken in the powder camera, as an aid to indexing the powder film. X-ray powder data show strong lines at 5.72, 7.28, 3.243, 3.087, 3.031, and 3.958 Å. The specific gravity is 2.660 (obs.) and 2.670 (calc.). The indices of refraction are ω 1.631 and ϵ 1.652.

The analysis shows the following percentages: insoluble 9.44, P_2O_5 38.11, Fe_2O_3 21.42, Al_2O_3 0.10, Mn_2O_3 none, FeO none, BeO 7.26, MnO 5.99, MgO 1.14, Na_2O 0.84, K_2O trace, F trace, H_2O 14.90, total 99.20.

The mineral is named in honor of Joseph J. Fahey, geochemist of the U. S. Geological Survey.

NATIVE LEAD, PRESIDIO COUNTY, TEXAS

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Approximately 3000 pounds of ore containing native lead was recovered from three small tabular ore bodies in the western part of the Shafter District, Presidio County, Texas. Two of the ore bodies were veinlike in limestone with clay gouge walls. The metallic lead was localized at the centers of the veins. The third ore body was flat lying disk-shaped about 4 feet thick with a surface area of 1600 square feet. The native lead occurred along a part of the margin of the ore body in a zone about 9 inches thick separated from the wall rock by clay gouge.

The ore generally was argentiferous steel galena partly or completely altered to cerussite and anglesite with minor minerals including wulfenite, litharge (?), quartz, and limonite. The native lead occurred as threads, sheets, to half an inch thick, and pods up to 4 by 7 by 2.5 inches.

The native lead appears to have been derived from the secondary minerals. Microscopic, chemical, and spectrographic data are presented, and the paragenesis of the mineral suite is discussed.

GEOLOGY OF THE HANOVER QUADRANGLE, NEW HAMPSHIRE-VERMONT

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The Hanover quadrangle of west-central New Hampshire and east-central Vermont straddles a belt of cleavage domes on the west and of Oliverian granitic domes on the east. The latter are represented within the area by the synkinematically intruded Devonian (?) Lebanon granite which has been forcibly injected upward and southeastward. Surrounding metamorphics have been granitized, and the beds south of the intrusive have been overturned. The cleavage domes are represented by the Pomfret dome, an unusual structure thought to be due to the uparching of already folded rocks by a rising granitic or migmatitic massif.

Ordovician(?) eugeosynclinal metamorphics underlie most of the quadrangle. These consist of the "Vermont sequence" (Waits River and Gile Mountain formations), and the "New Hampshire sequence" (Orfordville formation). The latter is thought to overlie and be a partial equivalent of the Gile Mountain formation, but the evidence is not unequivocal. A revision of the stratigraphy of the Orfordville formation as first described by Hadley (1942) is also necessitated by the geologic relations within this quadrangle.

Three thrust faults disrupt the structure. Two of these, the Monroe and Northey Hill, are premetamorphic, and recognized only with difficulty. The third, the Ammonoosuc, is a clearly defined shear thrust.

LEACHING OF WISCONSIN GLACIAL GRAVELS IN EASTERN NORTH AMERICA

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Time is one of the many factors that have determined how deeply a drift deposit is leached of its limestone. Other factors obviously include (1) amount of limestone originally present, (2) size of the limestone particles, (3) permeability, (4) topographic position in relation to water table, (5) slope of the surface, (6) amount and concentration of rainfall, (7) temperature and type of vegetation. Gravel was used for study as it served to offer a yardstick to subdivide the Wisconsin. Gravel pits in flat-topped hills were used; pebble counts were made to determine the percentage of limestone, and the base of the leached zone was placed where the sandy matrix of the gravel effervesced to dilute HCl. Since there is normally some variation within a single pit, both the shallowest and the deepest amount of leaching was recorded.

The observations fall into a simple pattern of three belts: a southern belt leached 11 to 13 feet a middle one leached 5 to 8 feet, and a northern belt leached 1 to 4 feet. Within each belt, where the drift contains limestone, the depth of leaching is fairly constant, even though the percentage of limestone varies considerably, The study therefore suggests that depth of leaching is a fairly good criterion of age; and that the southern belt (leached 11 to 13 feet) is Tazewell, the middle belt is Cary, and the northern belt is Mankato.

This would make the Olean of New York, and the drift of Northeast New Jersey and Long Island Tazewell; the Valley Heads, the Binghamton, and the "upper" drift of New England and coastal Gaspe Cary; and the drift south of Lake Ontario and north of the Adirondacks and Southern Quebec Mankato.

STRUCTURAL EVIDENCES FOR THE PRESENCE OF A WARPED PENEPLANE UNDER THE NORTH CAROLINA COASTAL PLAIN

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Examination of well logs and geophysical data from the Coastal Plain of North Carolina, and the construction of cross sections in the area introduce the concept that either one considerably warped or two separate peneplanes exist below the sediments. Studies of the slopes involved indicate that the surfaces cannot readily be correlated with current recognizable peneplanes of the Blue Ridge and the Valley and Ridge areas to the northwest. Rather, these seem to be a warped single surface whose slope has been exaggerated by downward adjustment due to compensation for the additional weight of the Coastal Plain sediments. It is believed that the adjustment took place during the whole period of deposition of the materials.

GEOLOGY OF THE GYPSUM DEPOSITS NEAR SUN CITY, BARBER COUNTY, KANSAS

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An area of approximately 4 square miles, in the vicinity of the Pioneer Mine, Sun City, Kansas, was mapped to ascertain the relationship between the Medicine Lodge gypsum and anhydrite. Samples were studied petrographically.

The Medicine Lodge gypsum (lower Permian) forms the cap rock in the area. The regional dip is southwest about 11 feet per mile. Structural contours on the base of the gypsum show local irregularities which may represent initial dip.

Anhydrite is not generally present on surface outcrop but is exposed in the mine. It occurs as

lenticular deposits about 10 feet above the base of the gypsum. The gypsum is about 30 feet thick in the mine. Where anhydrite is absent, solution channels generally are present. These channels are zones of brecciation in which the gypsum is soft, porous, sugary, and coated with some clay. Drilling has encountered water in these channels.

Petrographic studies show (1) gradation of anhydrite to gypsum; (2) gypsum fracture filling in the anhydrite; (3) absence of anhydrite in the upper and lower part of the gypsum; and (4) no evidence of distortion.

Hydration of this anhydrite may have taken place subsequent to the sedimentary anhydrite-gypsum deposition.

PLEISTOCENE AND RECENT SEDIMENT FROM THE FLOOR OF THE NORTHEASTERN PACIFIC OCEAN

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Seven dredge hauls on seamounts, and nine cores of the sea floor show that glacial marine drift was deposited over several hundred thousand square miles of the northeastern Pacific during Pleistocene time. Some ice-rafted pebbles are covered by as much as 50 mm. of manganese dioxide suggesting a minimum age of 50,000 years.

Since glacial marine sedimentation ceased, blue mud has spread out from shore. The drift is covered by at least 127 cm. of blue mud at a distance of 250 miles from shore. Southeast of Kodiak, Alaska, blue mud is covered by a thin layer of ash from the 1912 eruption of Katmai Volcano.

Pebbles surrounded by envelopes of well-sorted coarse sand are incased in pieces of a thick manganese crust from Gilbert Seamount. The formation of the envelopes is ascribed to the action of weak currents although the specimens were dredged from a depth of at least 3600 feet.

CLASSIFICATION, DELINEATION, AND MEASUREMENT OF NONPARALLEL FOLDS*

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Simple folds are divided into cylindrical and noncylindrical classes, both of which are subdivided into three genera—parallel, similar, and cognate folds. Cylindrical folds have cylindrical stratigraphic surfaces, over some stated or implied longitudinal limit; and no restriction is placed upon their curvature. Parallel folds have parallel or approximately parallel surfaces; and concentric folds are eliminated as a misnomer. Similar folds have surfaces that accord with the mathematical meaning of similarity. Cognate folds have surfaces that are nonparallel, noncongruent, and nonsimilar. Noncylindrical folds have no axial lines or axial planes.

Many illustrations are given of idealized cylindrical folds, by showing sections normal to the axial line. The traces of stratigraphic surfaces are shown as elliptic arcs, which, for stated reasons, are preferred to parabolic or hyperbolic arcs. Thickening, thinning, and the disappearance of strata, either at the apices or along the flanks of folds, are illustrated, and supratenuous folds are shown to be a subspecies of similar and cognate folds.

A suite of ellipses, with eccentricities ranging from 0.312 to 0.999, is presented, together with photographic reductions of these. Eroded folds are reconstructed by fitting elliptic arcs tangentially to dips plotted along suitable profiles. The stratigraphic thickness of similar and cognate folds is defined as the area between selected elliptic arcs, divided by the length of a median arc. This area is readily obtained from a simple formula, but arc lengths require a table of elliptic functions. A set of semiperimeters, for a major semiaxis $a = 20$, has been computed as an aid in such work.

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* Publication authorized by the Director, U. S. Geological Survey

MINERALIZATION AND ROCK ALTERATION IN THE ELIZABETH COPPER DEPOSIT, VERMONT

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The Elizabeth copper deposit is located in Orange County, approximately 10 miles west of the Connecticut River. It is in the southern end of the "Vermont Copper belt" in the western portion of the Green Mountains. It is a hydrothermal replacement predominantly in a favorable stratigraphic horizon. The country rock is chiefly mica-garnet schist with thin quartzite beds. A key horizon is an amphibole rock, containing common green hornblende, carbonate, quartz, and feldspar. The favorable ore horizon is a tremolite-phlogopite-carbonate rock, probably originally a limestone bed in the siliceous sediments.

The main ore minerals are pyrrhotite and chalcopyrite associated with minor amounts of sphalerite, pyrite, galena, molybdenite, and cubanite. The most important gangue minerals are tourmaline, rutile, and idocrase. Post-ore faults are filled by calcite, pyrite, and quartz.

Sericitization is dominant in the north end and down the northerly plunge of the ore body. It is associated with slight silicification. To the south the silicification is more pronounced. Adjoining the ore a zone up to 1 foot wide consists of fine-grained quartz and albitic feldspar. The hornblende of the regional amphibolite has been altered to biotite forming rosettelike pseudomorphs. In the host rock tremolite has been altered to phlogopite and talc. Feldspar shows a slight saussuritization. In addition there is an increase in silica.

INSHORE MARINE MAGNETIC INVESTIGATIONS: THE AREA FROM NEW JERSEY TO CAPE COD, MASS.

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The total intensity of the earth's magnetic field was measured from a ship along various tracks from New Jersey to Cape Cod to a distance about 30 miles from shore. The measurements were made with a continuously recording airborne magnetometer which had been modified to be towed about 30 feet under water 200 or more feet astern the survey vessel. This survey shows that there is no magnetic anomaly associated with the inshore end of the Hudson Canyon. It found major anomalies of several hundred gammas magnitude covering large areas 10 miles east of Sandy Hook, N. J., south of Fire Island and south-southwest and north-northeast of Block Island. A nonanomalous region was found south of Narragansett Bay. The half widths of smaller anomalies are the order of fractions of a mile at the Cape Cod end of the area, while in the area south of Long Island they had half-widths of the order of miles. It is concluded that there is no major structure at the surface of the crystalline rock under the Hudson Canyon near shore. The Narragansett Basin extends south under water at least 10 miles. Several hypotheses concerning the subsurface crystalline rock in the area are proposed.

PEDOLOGY AS AN AID FOR INTERPRETING THE ALLUVIAL TERRACE SEQUENCE IN WYOMING*

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Modern soils and paleosols have proved useful for establishing the stratigraphic and chronologic relationships of alluvial terrace deposits along streams flowing eastward from the Rocky Mountains

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in Wyoming. The soil of the highest terrace is characterized by a thin A horizon, columnar structure, and concentration of $CaCO_3$ in the B horizon, whereas profile development on the two lower terraces is less marked. In addition, a geographically widespread paleosol, buried by alluvium beneath the surface of the high terrace, provides an especially useful horizon marker for terrace correlation. The paleosol is characterized by a well-defined zone of $CaCO_3$ (up to 30%) and/or gypsum accumulation, which was developed on topography different from the present and is traceable across several lithologies.

On the basis of the soil development on various terrace surfaces, stratigraphic relations of the paleosol, and relationship to glacial features in the near-by mountains, the terraces are interpreted as the result of alternate periods of aggradation and degradation caused by climatic shifts after the Megathermal period.

One significant result of this study is demonstration of the fact that field identification of paleosols is ordinarily difficult and therefore should be supplemented with laboratory work. Laboratory techniques which provide distinctive criteria for soil formation are discussed; these include a quick test for $CaCO_3$ content of soils, and an X-ray procedure for determining the extent of weathering of mica and formation of clay minerals.

The problems involved in dating soils and in using pedology to interpret past environments are discussed.

URANIUM ORE CONTROLS IN THE HAPPY JACK MINE AND VICINITY, WHITE CANYON, UTAH

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Channels within the Triassic Shinarump formation are thought to be the primary uranium ore control in White Canyon, southeastern Utah. This has been demonstrated in the Happy Jack Mine and on the Sunrise and Gonaway claims. In addition, there are important intrachannel controls; the most conspicuous are carbonaceous matter and lithologic changes.

Shinarump stream channels were first mapped in White Canyon during 1951, on the basis of outcrop mapping alone. Three of these channels—the Happy Jack, Sunrise, and Gonaway—were later explored and extended by drilling. Detailed geologic mapping of the Happy Jack mine and drill-hole information supplemented each other.

A structural contour map of the base of the Shinarump, corrected for regional dip, was the most important tool in locating ore. Each drill site was located only after the preceding diamond-drill core information had been evaluated and placed on the contour map. Forty five per cent of the holes drilled were situated in ore, resting on or near the bottom of channels. No ore was found in this area outside of channels. Correlations among diamond drill holes and outcrops reveal that the ore is characteristically in a porous carbonaceous sandstone on top of Shinarump siltstone.

Cross sections of the Happy Jack mine show, in addition to the above features, horizontal bedding-plane control for pitchblende and sulfide mineralization. There is no evidence for vertical control of primary ore.

SOME SPECIAL CRITERIA FOR GRANITIZATION

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In addition to textures, replacement features, structural and stratigraphic continuity with, and chemical relationships to country rocks, the following criteria appear useful.

Early epidote commonly occurs in amphibolitic-derived granitized rocks, either inherited, or formed by early-metasomatic partial biotitization of hornblende. It antedates part of the plagioclase and

all of the late K feldspar. Its preservation indicates temperatures below those of any silicate melt. Microscopic relations between early epidote and feldspar differ greatly from those between feldspar and secondary epidote.

Early epidote and other minerals assign a considerable part of the granitized rocks to temperatures lower than those of the high-grade zone. Mapping of progressive zones leads to the concept of *external and internal zoning*, some isograds being outside and others inside the granitized body. At igneous contacts, all progressive zones are external.

Some relict minerals in granitized rocks are also chemical indicators of nonmagmatic origin. *Al-silicates* have been previously discussed. Sometimes *lime-silicate minerals* survive. Chemical incompatibility of certain minerals with the bulk rock composition suggests granitization.

Many granitic rocks have unequivocally crystalloblastic, some indubitably igneous textures. *If crystalloblastic and igneous appearing features are combined, time analysis* is decisive. If igneous textures are older, an igneous rock has been altered autometamorphically or metamorphically. If crystalloblastic textures are older, a granitized rock has eventually developed certain igneous features. Final liquification destroys all crystalloblastic and creates new igneous textures. Intrusive emplacement does not prove liquification.

Chemical similarity of advanced granitized and igneous granitic rocks indicates close genetic connection, rather than two geologically unrelated origins. Probably the quantitatively apparently subordinate, true igneous granitic rocks mostly form by liquification of granitized rocks. Granitization converges toward a chemical equilibrium in the crust.

PITCHBLENDE DEPOSIT AT THE CARIBOU MINE, BOULDER COUNTY, COLORADO

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Pitchblende occurs at the Caribou mine in a mesothermal carbonate vein that contains silver, lead, and zinc minerals. Unlike most of the large, well-known pitchblende deposits of the world, it does not contain nickel- and cobalt-bearing minerals. The deposit is believed to be unique in that the host rock is a Tertiary monzonite. The pitchblende is in a tension fracture (the Radium vein) of an interconnecting vein system, at vertical depths between 875 and 1075 feet. Two pitchblende ore shoots are known; the largest one has a vertical dimension of 200 feet and a horizontal dimension of 70 feet. Within the ore shoots, pitchblende forms a discontinuous seam as much as 6 inches thick along the side of sulfide veins. The sulfides and the pitchblende are not intergrown. There is no apparent difference in mineralogy, other than the presence of pitchblende, between the pitchblende-bearing vein and the other veins in the system. The pitchblende is predominantly a soft, sooty variety, but the larger masses also contain a hard, botryoidal variety. The soft pitchblende is believed to have been deposited later and at a lower temperature than the hard pitchblende.

CHEPULTEPEC AND LONGVIEW LIMESTONES (ORDOVICIAN) IN SOUTHWEST VIRGINIA

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The limestone beds of the Chepultepec and Longview formations have been confused in parts of southwest Virginia. In the vicinity of Blacksburg and Saltville, Virginia, they now have been traced over distances great enough to indicate that considerable thicknesses of dolomitic limestone separate them.

The limestone lithofacies of the Chepultepec occurs only a short distance above the highest, thick sandstone beds of the Knox group and includes many interbeds of dolomite. The dolomitic limestones above the Chepultepec limestone contain less quartz sand than those below. A thick, white chert bed

commonly is present at or near the base of the Longview limestone, and *Lecanospira* is most abundant in the lower beds of this formation.

Measured sections are presented to show the stratigraphic relationships between the two limestones along the strike belt.

EFFECT OF CARBON DIOXIDE ON THE SOLUBILITY OF SOME SUBSTANCES IN SUPERHEATED STEAM AT HIGH PRESSURES

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An apparatus has been constructed which makes it possible to study the gaseous solubility of substances in a mixture of about 94 per cent water and 6 per cent carbon dioxide at temperatures up to 600°C. and pressures up to 2000 bars. The corrosive character of this mixture introduces some experimental difficulties, which have largely been overcome. The presence of carbon dioxide affects the gaseous solubility of all substances tried.

MUDLUMPS AT THE MOUTHS OF THE MISSISSIPPI RIVER

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Mudlumps are a physiographic phenomenon unique to the delta of the Mississippi River. They are elongate upswellings of poorly sorted sediment, composed predominantly of clay-sized particles. Localized forces, arising from the static pressure of accumulating sedimentary deposits, are relieved through the upwarping of near-surface sediments. Many mudlumps are forced above the water surface to form islands, some approaching 30 acres, but the majority occur as submarine eminences. Mudlump islands have cores of plastic clay which may arise from depths as great as 300 to 500 feet. Surrounding and often capping the clay cores are stratified recent sediments of the original bar or bay bottom. The strata typically delineate doubly plunging anticlinal structures. Tensional fissures and faults paralleling the strike of the elongate islands are common. Mud, gas, and salt water are discharged from vents along the faults, often building low, flat cones. A positive correlation exists between mudlump growth, mudvent activity, and active sedimentation at each of the several passes. South and Southwest Passes, which have been modified by means of jetties, display an arc of mudlumps outside and parallel to the periphery of the bar deposits. On natural passes, mudlumps are affected by submerged natural levees as well as the bar deposits. Though often exhibiting several periods of uplift, individual mudlump islands are temporary features, either being removed by wave erosion in a few years or else becoming incorporated into the rapidly growing marshland.

BRANCHING RATIO OF K^{40} RADIOACTIVE DECAY AND ITS APPLICATION TO GEOLOGICAL AGE DETERMINATIONS

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The ratio of K-capture to beta-emission for the naturally occurring radioactive isotope K^{40} has been determined by extracting, purifying, and measuring the volume of argon extracted from four different samples of microcline. The amount of radiogenic A^{40} was ascertained by mass spectrometric analysis. The potassium contents of the samples of microcline were determined by chemical analysis. The argon was extracted by heating with metallic sodium in vacuum, and it was purified by treating the gas in a calcium furnace to constant volume. Isotopic analysis of argon thus obtained showed that the different samples contained from 93 to 100 per cent of radiogenic argon.

All the samples of microcline used in this investigation were from the Grenville area where ages ranging from about 850 to 1050 m.y. had been determined by uranium-lead methods. As the localities from which these samples were collected are not precisely dated, they have been assumed to be of the same age as Wilberforce (1030 m.y.). Using the total half life for K^{40} of 12.7×10^8 years as obtained by Sawyer and Wiedenbeck, the values of branching found were from 0.053 to 0.066. These are in good agreement with the low range of values obtained by counting experiments and also with those obtained by Aldrich and Nier. But if any of the sample had a younger age (for example 850 m.y.) then the values for the branching ratio would be raised and would still be within the range of other physical determinations.

Work upon more precisely dated material is being continued in the hope that the branching ratio can be more precisely fixed and a useful method of determining ages established.

THE α-EUCRYPTITE PROBLEM

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Massive granular α-eucryptite is reported from two new pegmatite localities, Center Strafford, New Hampshire, and the Harding mine, Dixon, New Mexico. The Center Strafford material is an intergrowth of α-eucryptite and albite, identical with that described by Brush and Dana (1880) from Branchville, Connecticut. The Harding material is white to pale gray with a waxy luster. Hardness 6½. Specific gravity 2.64. Optically uniaxial positive (+) with $n\omega = 1.573$ and $n\varepsilon = 1.583$. Analysis gave: Li_2O 8.36, CaO 0.19, Na_2O 0.62, K_2O 0.38, Al_2O_3 35.76, SiO_2 54.64, total 99.95; measured cell contents: $Li_{4.8}Al_{4.8}Si_{6.8}O_{24}$. The strongest x-ray powder lines: 3.35 (10), 3.93 (9), 1.37 (9), 2.74 (8).

Crystals of synthetic α-eucryptite, averaging 5 to 8 mm. in length and 0.5 to 1.0 mm. in width, were made hydrothermally (by G. C. Kennedy). Hardness ~6, Hexagonal-R; hexagonal-scalenohedral. Observed forms: c {0001}, m {10$\bar{1}$0}, a {11$\bar{2}$0}, r {10$\bar{1}$1}, e {01$\bar{1}$2}, f {02$\bar{2}$1}, v {21$\bar{3}$1}. Unit-cell dimensions: $a_0 = 13.54$Å, $c_0 = 9.01$ ($a_0:c_0 = 1: 0.6654$); space group: $D_{3d}^5 - R\bar{3}m$. The optical and x-ray data are identical with those of the Harding material. Analysis gave: Li_2O 9.65, Al_2O_3 43.75, SiO_2 46.70, total 100.10; measured cell contents: $Li_{4.9}Al_{4.8}$ $Si_{5.9}O_{24}$. Treating the composition as derivative from SiO_2 (or $Si_{12}O_{24}$), the general formula can be written $(Si_{12-x}, Al_x)(Li_{x-y}Al_{y/2})O_{24}$ where $x = 5.1$ and $y = 0.6$ in the Harding material, and $x = 6.1$ and $y = 1.2$ in the synthetic material. The mechanism of compositional variation is interesting in that there is a coupled interstitial entrance of 3Li + Al to provide valence compensation for Si = Al instead of alkali alone as in the tridymite-christiansenite and high-cristobalite—alpha-carnegieite series.

Both natural and synthetic α-eucryptite fluoresce begonia rose (Ridgway) in short-wave ultraviolet radiation. In the direct x-ray beam the natural material fluoresces pale shrimp pink; the synthetic, begonia rose. When irradiated, both become pale smoky.

PALERMOITE AND GOYAZITE, TWO STRONTIUM MINERALS FROM THE PALERMO MINE, NORTH GROTON, NEW HAMPSHIRE

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Palermoite, a new species having the composition $(Li, Na)_4SrAl_9(PO_4)_8(OH)_9$, and goyazite, $SrAl_3(PO_4)_2H_2O$, occur as late hydrothermal products in open cavities at the Palermo pegmatite, North Groton, New Hampshire.

Palermoite is orthorhombic, long prismatic in habit with {001}, {010}, {011}, {130} and {110}. The prism zone is vertically striated. Unit cell dimensions: $a_0 = 7.31$Å, $b_0 = 15.79$, $c_0 = 11.53$ ($a_0: b_0: c_0 = 0.4630:1:0.7320$) with the space group D_{2h}^{25}-Immm. Cleavage {100} perfect, {001} fair.

Fracture fibrous to subconchoidal. Brittle. Hardness 5½. Specific gravity 3.22 (meas.), 3.20 (calc. for two formula-units per cell with Li:Na = 4.9:1). Colorless to white. Luster vitreous to subadamantine. Streak white. Fluoresces white in direct x-ray beam. Optically biaxial negative (−) with nX = 1.627, nY = 1.642, nZ = 1.644; 2V = ∼20°; r < v, moderate; X = c (elongation), Y = a, Z = b. Analysis gave: Li_2O 3.70, Na_2O 1.56, K_2O 0.10, CaO 0.88, SrO 9.20, Al_2O_3 33.85, P_2O_5 44.64, H_2O 5.97, total 99.90. The strongest x-ray powder lines are 3.11 (10), 4.38 (9), 2.44 (8).

Small colorless to white rhombohedral crystals of goyazite, pseudocubic {10$\bar{1}$2} terminated by {0001} and truncated by {20$\bar{2}$1} and {11$\bar{2}$0} occur in association with palermoite. Unit cell dimensions on Palermo crystal: a_0 = 6.98Å, c_0 = 16.54 (a_0: c_0 = 1: 2.3696). Specific gravity 3.15. Optically uniaxial positive (+) with nO = 1.640 and nE = 1.651, showing anomalous biaxial character with 2V up to 20°. The strongest x-ray powder lines: 2.97 (10), 2.20 (8), 1.89 (7).

The mineral association includes siderite, childrenite-eosphorite, green fibrous beraunite, crandallite-deltaite (?), whitlockite, brazilianite, tiny white hexagonal prisms of apatite, and small quartz crystals. Palermoite and goyazite appear in the sequence after siderite, but before apatite and quartz.

GLACIAL HISTORY OF THE NAKNEK DISTRICT, ALASKA PENINSULA, ALASKA

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Four Quaternary glaciations, successively less extensive, are described in the Naknek districtd southwestern Alaska. Glaciers exist today only on high peaks east of the district, but lake-fillee glacial troughs transect the western foothills of the Aleutian Range, and glacial deposits underlie th adjoining coastal lowlands.

A drainage divide underlain by till, near Halfmoon Bay, 23 miles west of Naknek Village, represents the earliest and most extensive recognized glaciation. The till contains boulders from the Jurassic Naknek formation which crops out 75 miles east in the Aleutian Range. Relatively great antiquity is suggested by altered topography of the moraine, by its position with respect to younger moraines nearer the mountains, and by the induration of the till. Johnston Hill, 13 miles southwest of Naknek Village, is the most prominent moraine remnant of the second recognized glaciation. Although marshes are numerous, drainage of this moraine belt is relatively well integrated. Till knolls, such as Mak and Air Hills, 8 miles east of Naknek Village, and lateral moraines preserved above the level of subsequent glaciation represent a third advance.

End moraines of the latest major glaciation enclose lake-filled glacial troughs in the foothills. Minor fluctuations of the ice front produced recessional moraines, the most prominent of which encloses Iliuk Arm, a headwater bay of Naknek Lake. Moraines of the latest major glaciation are correlated with similar moraines in the Cook Inlet lowland and parts of the Alaska Range, on the basis of relative topographic prominence, preservation, and physiographic position.

X-RAY STUDY OF RENIERITE, GERMANITE, AND COLUSITE

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X-ray powder photographs of reniérite, germanite, and colusite show them to be essentially isostructural. There are slight but consistent differences in the edge of the unit cells, and reniérite further shows some divergence from a true isometric pattern, accounting for the strong anisotropism observed in polished section. The average values of a_0, using both CuK_α and CoK_α filtered radiation, are as follows:

Colusite 10.62± Å, germanite and reniérite 10.57± Å. The value for germanite is twice the published figure (5.299 Å), and that for reniérite is new.

Intensities for all three correspond very closely, with the exception of one group of lines, where there is a consistent difference.

Form	*Intensity*		
	Colusite	Germanite	Reniérite
{002}	2	1	1
{012}	2	½	1
{112}	2	2	2

All lines can be satisfactorily indexed except in reniérite, where members of definitely resolved doublets at 1.33± Å, 1.08± Å, and .9390± Å cannot be so indexed, and suggest strongly that the mineral is pseudo-isometric.

MINERALOGY OF THE SERPENTINE GROUP

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An investigation of the stability, morphology, and structure of a number of serpentine and serpentinelike minerals has resulted in a more critical evaluation of the fundamental properties of the end members chrysotile and antigorite, and in more information as to the nature of certain related minerals.

Chrysotile asbestos is less stable than antigorite as shown by treatment with HCl and analysis of the results by *x*-ray and differential thermal patterns, electron micrographs, and solubility data. Since nitrogen-adsorption measurements reveal no significant difference in the surface area of the test samples, the difference in solubility may be the result of greater strain in the outer layers of chrysotile tubes than is present in the flat antigorite plates. Hydrothermal treatment of finely ground chrysotile fibers produces a flaky substance resembling antigorite.

Using the effect of 1N HCl treatment upon the 001 *x*-ray reflection, a method was devised statistically which provides a means of evaluating the percentage of chrysotile and antigorite in mixtures. This method has shown that serpentines other than chrysotile and antigorite are usually mixtures of these two minerals.

A fibrous form of bementite found to be a manganese mineral analagous to chrysotile and ectropite may be a similar analog of antigorite.

Deweylite seems to consist of a crystalline serpentine phase plus an amorphous complex of magnesia, silica, and water.

FAULT PATTERN OF THE MISTASSINI REGION, NORTHERN QUEBEC

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In the Mistassini region of Northern Quebec, Proterozoic sedimentary rocks are truncated by northeast-trending Grenville gneisses. Within the basin of Lakes Mistassini and Albanel, the gently dipping sedimentary rocks have an arcuate structure which is reflected in a regional northeast strike and southeast dip. East of Lake Albanel the rocks are deformed, and the beds dip from 35° to vertical. Five to 8 miles east of Lake Albanel, the sedimentary rocks terminate against a complex of gneisses with which they cannot be related. Other workers have suggested that the gneissic rocks are in contact with the sedimentary rocks along a northeast-trending, high-angle thrust fault or zone of faults.

The writer's mapping supports the inference of a northeast fault zone in the Mistassini region.

Although only one fault contact of the sediments and gneisses was seen during field work, considerable information was gained both from bedrock relations and from an analysis of linears appearing on air photos. Four principal sets of linears were recorded, and these form a pattern which must be related directly to regional forces. The pattern is interpreted to indicate that major crustal forces in late Precambrian time were directed toward the northwest and resulted in shear fracture in the crust in a direction approximately N.50°E. Linears at N.35°E. and N.65°E. may represent shear fractures developed under the same compressive forces.

CRETACEOUS STRATIGRAPHY OF THE TAMPICO EMBAYMENT WITH EMPHASIS ON THE REEF FACIES OF THE ALBIAN-CENOMANIAN

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The areal distribution and geomorphologic influence of outcropping Cretaceous formations in the Tampico embayment of Mexico are reported on the basis of reconnaissance mapping covering a 3-degree quadrangular area, from Latitude 20°N. to 23°N. and from Longitude 96°30′W. to 99°30′W. Stratigraphic sequences in type sections in the area are reviewed, as are the tectonic elements that exposed them.

Criteria are proposed to define the bio-facies and litho-facies of the Albian-Cenomanian, and their paleoecology and growth units are correlated. Dolomitization of some Middle Cretaceous limestones in the Tampico region is substantiated, contrary to Muir, and is shown to be one factor controlling porosities of the producing reef formations. Evidence is offered of the existence of a sublittoral, back-reef dolomitic facies for which the name *Tamiahua* has been proposed. Its zonal distribution, based on the geochemical analyses of 80 core samples, is presented for the Poza Rica oil field by means of curves joining equal points of $MgCO_3$ values, termed "isodols" by the author. The main interreef facies, El Abra, is subdivided into five stratigraphic zones. The neritic fore-reef facies, Tamabra, and the dense bathyal facies, Tamaulipas, are also given specific definition.

New oil seeps are reported and described in the fractured Agua Nueva formation (basal Turonian) in the Xilitla area, 28 km. northwest of Tamazunchale. Interdigitation of Agua Nueva with El Abra, as observed in outcrop and cores, is explained as a depositional phenomenon. The extraordinary 2550-meter thickness of the reef facies penetrated by the famous Penn-Mex well, Jardin No. 35, in the "Golden Lane" is considered a duplication of section, following a study of old well records and cores.

GLACIAL SEQUENCE IN THE MISSION VALLEY, WESTERN MONTANA

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The glacial deposits of the Mission Valley record three Wisconsin advances of a large intermontane lobe of the Cordilleran ice sheet. There is no record of pre-Wisconsin glaciation in the valley.

The early Wisconsin substage is represented by a weathered clay-rich till found in the southern portion of the valley. The terminal moraine of the mid-Wisconsin substage is a broad ridge of clay-rich till near the center of the valley. Extensive lacustrine and fluviatile deposits in the valley are also of mid-Wisconsin age. The late Wisconsin terminal moraine, at the south end of Flathead Lake, is a massive ridge of poorly sorted sand and gravel. It is bordered on the south by an extensive outwash plain.

The late Wisconsin terminal moraine was formed subaerially and was later covered by the waters of Glacial Lake Missoula. The lake was very late Wisconsin. This sequence implies that the maximum

late Wisconsin advance was reached in the Mission Valley before the corresponding event in the Pend Oreille Lake region of Idaho.

Glaciation of the Mission Valley by ice flowing southward from a Canadian ice cap was accompanied by local mountain glaciation in the adjacent Mission Range. Periods of maximum glacial advance in the Mission Range were contemporaneous with those in the Mission Valley.

GEOPHYSICAL INVESTIGATIONS IN THE EMERGED AND SUBMERGED ATLANTIC COASTAL PLAIN. PART VII: THE CONTINENTAL SHELF, CONTINENTAL SLOPE, AND CONTINENTAL RISE SOUTH OF NOVA SCOTIA

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The results of a series of 25 refraction profiles made over the continental shelf south of Nova Scotia and extending down to the adjacent deep basin are reported. The shelf profiles are similar to those obtained elsewhere along the Atlantic Coastal plain, showing an unconsolidated sediment, a semiconsolidated sediment, and a crystalline basement. The sediments gradually thicken seaward up to 2.0 km. (6500 ft.). On the continental shelf southeast of Halifax, Nova Scotia, a lens of higher-velocity sediment is present below the semiconsolidated sediment with a maximum thickness of 2.7 km. (9000 ft.). There is a downbuckle in the basement under the continental slope and a corresponding increase in the total thickness of sediments up to 5.0 km. (16,000 ft.) on the continental rise. The sediments then thin farther seaward with the younger sediments overlapping the older. On the profiles over the continental rise the intermediate layer of seismology was measured at an average depth of 10 km. (33,000 ft.) and an average velocity of 6.9 km./sec. (23,000 ft./sec.), and on one profile the Mohorovicic discontinuity was measured at a depth of 16 km. (52,000 ft.).

GEOLOGIC PROBLEMS OF THE SOUTHEAST MISSOURI LEAD BELT

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This paper is essentially a progress report on the geological study being made in the southeast Missouri District by the St. Joseph Lead Company. The problems encountered are described together with an assessment of the progress toward their solution. These problems have consisted of the subdivision of the Bonneterre formation into units that can be mapped underground, the recognition of the structural controls of the ore trends, the recognition of the types of rock alteration accompanying or preceding ore deposition, and the collection of data which may indicate the method of ore genesis.

The Bonneterre formation is divided into eight principal zones which are numbered from top to bottom. Contacts between zones are mapped, and structural features are indicated by contouring. Ore in each zone has distinctive characteristics.

Buried Precambrian igneous knobs have localized some ore bodies in the Lead Belt area, but sedimentary arch structures of depositional origin are the outstanding features controlling ore trends. Fracture zones exerted a secondary influence where arches are present and, where arches are absent, were the dominant ore-controlling structures.

Major alteration effects are dolomitization of limestone, "fingering" and spotting, recrystallization, and removal by solution. Glauconite and adularia have been introduced or redistributed.

Lateral migration of the ore solution was important, and the vertical component of motion almost surely was up rather than down. The marginal position of sphalerite in the galena ore bodies is in accord with the relative solubilities of the two sulphides.

PUNCHED-CARD TECHNIQUES SPEED MAP MAKING*

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Punched cards are used to record for each datum point: the age of beds, the frequency and thickness for each lithology encountered. Various ratios, such as clastic ratios, are calculated electronically and automatically punched into cards. The punched cards, containing the original data and the calculated data, are arranged in order such that the data may be rapidly transferred to geologic maps.

Ratios calculated by this procedure are more accurate and may be obtained about 15 times faster than is possible by manual procedures.

This procedure has been used in the analysis of data for the paper given by Professor Harold Wanless on *Geographic and stratigraphic distribution of Pennsylvanian coal in the United States.*

MINERALOGY AND PETROLOGY OF THE MANGANESE DEPOSITS OF AROOSTOOK COUNTY, MAINE

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Syngenetic manganese occurs in sedimentary rocks of Ordovician (?) and Silurian age in Aroostook County, Maine, as two distinct types: (1) in bedded hematitic deposits in which braunite is the principal manganese mineral; and (2) in siliceous carbonate rocks in which ferroan rhodochrosite of variable composition is the principal manganese mineral. In the bedded hematitic deposits the braunite occurs as impure laminae and less commonly as impure nodules. Manganese carbonates, including rhodochrosite, are also associated with the hematitic deposits. In the siliceous carbonate rocks the ferroan rhodochrosite is in laminae composed largely of that mineral or in laminae containing abundant chlorite.

Minor manganese minerals consist of spessartite, rhodonite, bementite, pyrophanite, stilpnomelane, neotocite, and many inconclusively identified minerals some of which give x-ray patterns suggesting manganoan chlorite and talc. Other minerals in these deposits are quartz, feldspar, sericite, chlorite, muscovite, apatite, barite, phlogopite, calcite, dolomite, pyrite, pyrrhotite, and magnetite.

Occurrence, distribution, and paragenesis of some of the manganese minerals are discussed, and chemical analyses of rocks and minerals, with x-ray and spectrographic data are given. Comparison is made with deposits of similar mineralogy that have been described elsewhere.

EOCENE MAGMA SERIES OF THE BEARPAW MOUNTAINS, MONTANA†

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In the Bearpaw Mountains region of north-central Montana, early Eocene deposition of terrestrial sediments, probably equivalent to the Wasatch formation, was halted by uplift due to irruption of magma that continued intermittently through the rest of Eocene time. Four major volcanic formations and a great variety of intrusive rocks are provisionally assigned to two magma series. One of these series is represented by igneous rocks related to a monzonitic petrographic suite, and the other by igneous rocks related to a hyperalkalic shonkinitic petrographic suite. Metalliferous deposits and inclusions of Precambrian basement rocks occur in rocks of the monzonitic series. Rocks of both series occur also in neighboring mountains and can be correlated with those in the Bearpaw Mountains. Evidence supports the thesis that the undersaturated shonkinitic magma, through assimilation of basement rocks, gave rise to the magma series that formed the rocks of the monzonitic suite.

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PRECAMBRIAN TILLITE, MENOMINEE DISTRICT, MICHIGAN

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The Fern Creek formation, which underlies the Sturgeon quartzite ("Lower Huronian") in the vicinity of Fern Creek, Dickinson County, Michigan, was defined and very briefly described by the author in 1943. Remapping, new micropetrologic studies, and chemical analyses reaffirm the glacial character of these beds.

The 100-foot thick tillite member, containing 2 to 5 per cent of tillstones up to 6 feet in diameter scattered in a fine-grained nonbedded graywacke matrix, is in turn underlain by a thinly laminated member characterized by scattered rafted cobbles. This bed grades down into pebbly arkoses and coarse granite-bearing conglomerates which lie unconformably on a granite gneiss basement.

The tillite cannot be, by any correlation currently accepted, the correlative of the Canadian Cobalt (Gowganda) tillite. A second and earlier period of continental glaciation in the Precambrian of the Lake Superior region is thereby implied.

PRELIMINARY REPORT OF MULTIPLE GLACIATION IN THE BIG DELTA AREA, ALASKA

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At least three major Quaternary glaciations, each successively less extensive than the former, are recorded at the north end of the Delta River Valley, a pass through the Alaska Range of Central Alaska. Glaciers of the earliest recognized advance, the Darling Creek glaciation,* probably crossed the Tanana Valley in the Big Delta area and abutted against the Yukon-Tanana Upland to the north. End moraines are absent, but isolated remnants of till occur 3000 feet above the floor of the Delta Valley. Boulders in the till have no fresh surfaces, and the moraine retains no topographic expression.

During the next glacial advance, the Delta glaciation, the trunk glacier in Delta Valley, coalesced with smaller northward-flowing glaciers to form a piedmont lobe spreading about 30 miles beyond the front of the range. Moraines are dissected and subdued, and many former kettle-lakes basins are filled with sediments. Schist boulders, common in younger moraines from the same source area, are rare at the surface.

The latest major glacial advance, the Donnelly glaciation, extended about 15 miles north of the range. Ice was insufficient to produce a coalescent lobe, and distinct terminal bulbs spread northward onto the plain. Well-preserved end moraines with many lakes and fresh knob-and-kettle topography lie at the base of the range. The till contains many schist cobbles and striated and polished boulders.

Black Rapids glacier and other glaciers have had recent advances into the Delta Valley.

PRELIMINARY REPORT ON THE LATE QUATERNARY HISTORY OF THE FAIRBANKS AREA, ALASKA

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Frozen silts in valleys of the Yukon-Tanana Upland in the Fairbanks area of central Alaska reveal a complex history of deposition, erosion, freezing, and thawing during the past 20,000 years. A thin layer of organic silt (muck) more than 20,000 years old (radiocarbon) was deposited on auriferous

* The glaciation names are used merely as a means of reference and do not constitute formal nomenclature.

gravels in valley bottoms. A thick cover of loess then blanketed the country. Much loess was carried into creek bottoms, burying vertebrate remains. With abatement of loess deposition, creeks cut headward, incising the loess valley fill.

Muck accumulated sporadically to form a thick layer in valleys carved in loess. Fossils 12,000 to 16,000 years old (radiocarbon) occur in this muck, which also contains buried forests, mammal bones, and a few partial carcasses of extinct mammals. Some carcasses were long preserved in cold, damp silt before being frozen. Before the muck became perennially frozen, water percolated through it into underlying loess in valleys and reduced ferric to ferrous compounds that colored the loess green. It is believed much of the present permafrost formed after a large proportion of the muck had accumulated. During freezing more loess was deposited.

After this loess was deposited, erosion removed some muck from creek bottoms and gullied loess on slopes. Ice wedges, formed in muck during the freezing, melted down 2–5 feet. Much slope wash produced during warmer-climate erosion accumulated in valleys to form a thin muck. This muck, 3500 to 4200 years old (radiocarbon), is now frozen. Permafrost is forming today in fine-grained sediments in valleys.

NOTES ON THE DIFFERENTIAL LEACHING OF URANIUM, RADIUM, AND LEAD FROM PITCHBLENDE IN H_2SO_4 SOLUTIONS

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Two 5-pound samples from the "hot spot" of the pyritic dump of the Wood mine, a past producer of pitchblende near Central City, Colorado, showed Ra/U ratios that were abnormally high but nearly constant at about 150 times the equilibrium value for both samples in spite of a seven-fold difference in uranium contents. Analyses of oxidized but still black Katanga pitchblende before and after leaching in very dilute, dilute, and concentrated sulfuric acid solutions showed that: (1) UO_3 is preferentially leached with respect to UO_2, Ra, and Pb in all three solutions, (2) the resulting residual concentration of both radium and lead effected in the process is proportional to the total amount of uranium leached except in concentrated H_2SO_4, and (3) after leaching in concentrated H_2SO_4 the resulting residual concentration of radium relative to lead is much lower, as might be expected from data published by Lind, Underwood, and Whittemore in 1918 for the solubility of $RaSO_4$. Under similar leaching conditions unaltered pitchblende from Great Bear Lake lost only $\frac{1}{10}$ to $\frac{1}{15}$ as much uranium as the UO_3-rich Kantanga ore. Both laboratory and field results point to the same conclusion: in an oxidizing, highly acid environment uranium is rapidly leached, and both radium and lead tend to be fixed approximately proportionally in the process. These results help to explain (1) why UO_3-rich uranium minerals tend to give *maximal* Pb/U ages, and (2) why the search for high-grade uranium ore in and around abandoned sulfide mines known to have produced pitchblende in the past has been consistently disappointing.

ABUNDANCE OF Ba, Sr, Sc, AND Zr IN CHONDRITES AND ULTRAMAFIC ROCKS

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Twenty-one chondritic meteorites and a number of mineralogically related ultramafic rocks have been analyzed by the optical spectrograph for some elements believed to be restricted largely to the silicate phase of meteorites. The concentration of each of these elements remains remarkably uniform in chondrites, supporting the theory that meteorites had a common origin in both space and time. Analytical results and their implications in the Shattered Planet Hypothesis of the origin of meteorites are discussed.

In chondrites the following abundance values were obtained: Ba 0.0008%, Sr 0.0007%, Sc 0.0007%, and Zr 0.005%. The validity and accuracy of these results is discussed in some detail.

Some preliminary observations have been made on the abundance of lithium in chondrites and ultramafic rocks. This element shows a strikingly large abundance difference in these two materials and its concentration in chondrites is more than 20 times greater than that in ultramafics. Ba, Sr, Sc, and Zr do not show such extremely large abundance differences.

REBOUND PHENOMENA IN THE FT. UNION FORMATION AND THEIR INFLUENCE ON DESIGN

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Garrison Dam, a multipurpose rolled-earth structure being built under the direction of the U. S. Corps of Engineers, is located on the Missouri River 80 miles upstream from Bismarck, North Dakota. Foundation rock is the Ft. Union (Tertiary) and consists of partially consolidated materials ranging from fat clays to sands with the clays predominating.

It was early recognized that rebound would occur in the excavations for the control structures. Geologic evidence indicates removal of approximately 1000 feet of material which is substantiated by high-load consolidation tests. Tests on the clay-shales show that on unloading and submergence rebound occurs. Theoretical studies used in designing the structures were made to determine the amount of immediate and long-time rebound due to excavation unloading. Field data plotted in the form of rebound versus time were obtained from gages during and subsequent to excavation. Largest rebound measured to date is over 2 feet. Field curves check the immediate and the first part of the long-time original curves closely. Owing to early recognition of the rebound problem, bad effects of rebound have been held to a minimum. Horizontal yielding and separation along bedding planes occurred in the powerhouse foundation adjacent to deep vertical cuts; consequently subsequent cuts of similar type have been and will be preceded by yield cuts to minimize breakup of the foundation. Fracturing of a grout curtain by breakup of previously placed grout and opening of incipient joints by rebound has resulted in relocating grout curtains outside the effect of rebound or in the delay of grouting until these rebound effects may be minimized.

SEISMIC-REFRACTION MEASUREMENTS ON THE GRAND BANKS AND ADJACENT SHELVES

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A reconnaissance refraction survey of the Grand Banks, St. Pierre Banks, and Banquereau was conducted in the first 2 weeks of September 1951. Three partially reversed profiles on the Grand Banks indicate sedimentary layers ranging in total thickness from 2000 to 4500 feet, underlain by crystalline rocks with velocities of 16,000–18,000 ft/sec. On St. Pierre Bank a single partially reversed profile showed 8000 feet of sediment underlain by crystalline rocks with a velocity of 17,500 ft/sec. Similar results were obtained on Banquereau where 9000 feet of sediments overlies crystalline rock with a velocity of 15,500 ft/sec. A partially reversed profile in the channel between St. Pierre Bank and Banquereau indicates 15,000 feet of sediment overlying crystalline rock with a velocity of 20,500 ft/sec. These results suggest that the channel is structural in origin.

ORIGIN OF ROCK CREEK AND OWENS RIVER GORGES, CALIFORNIA

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Owens River and Rock Creek occupy subparallel canyons incised across a plateau of rhyolitic welded tuff immediately east of the central Sierra Nevada. Owens Gorge, relatively the older of the two, was excavated in part by overflow from Long Valley Lake during the late Pleistocene. Rock

Creek Gorge developed as the result of headward growth and capture of drainage formerly tributary to Owens Gorge.

Rocks exposed in Owens Gorge and in a tunnel driven by the Los Angeles Department of Water and Power provide new significant evidence on the glacial and volcanic history of the region. Only three glacial tills are present, rather than four as formerly believed, and the Sherwin glacial stage is older than the Bishop tuff rather than younger as evidence in the Mono Lake region suggested.

EQUIDAE OF THE TEXAS GULF COASTAL PLAIN*

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The Oakville, Fleming, and Goliad formations of the Texas Gulf Coastal Plain are of late-lower, middle, and late-upper Miocene age, respectively. Evidence consists of: close Oakville and Fleming stratigraphic and faunal relationship, presence of *Oxydactylus*, *Merychyus*, and *Floridatragulus* in the Oakville; *Desmathyus*, *Machaeromeryx*, *Floridatragulus*, *Tomarctus*, and *Diceratherium* in the Fleming with primitive *Teleoceras* and *Mastodont* in the upper but not the lower part. The Goliad fauna is advanced but contains primitive forms such as *Paradaphoenus* and *Talpa?* and *Calippus* near *placidus* but more primitive.

Merychippus does not occur in the Oakville, and no *Parahippus* has been found in the Fleming which, however, contains *Merychippus gunteri* and *M. insignis?*, *Neohipparion*, *Nannippus* (*gratus* group), *Protohippus* sp., two *Calippines* including *C. francisi*, and an ancestral *Hipparion?*. Horses of the Goliad include Pliocene? genera but are specifically distinct in nearly all instances.

The Gulf Coast Miocene faunas appear to be distinct from those of the North and West, indicating a separate faunal province with restricted communication but not complete isolation. Also, the Gulf Coast faunas provide evidence that the Pliocene? genera were not evolved from *Merychippus* at the end of Miocene time but rather were derived directly from *Parahippus*, as was *Merychippus*, at the beginning of middle Miocene time.

COMPARISON OF ROCK GLACIERS AND BLOCK STREAMS IN THE LA SAL MOUNTAINS, UTAH†

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Rock glaciers in the La Sal Mountains are lobes of coarse unsorted debris that lie in or below cirques They have smooth headward slopes merging with talus, hummocky medial slopes with longitudinal ridges and furrows, and a terminal zone of arcuate ridges and furrows ending in a steep front. The surface debris lacks obvious fabric and commonly rests on a core of till. Many have oblique crevasse-like furrows, deep kettlelike depressions, lateral ridges, and associated outwash deposits or channels. They are believed to be residual from small glacial readvances, retaining the essential configuration and structure of the ice. They are of Cary, Mankato, pre-altithermal.

The block streams are also lobes of coarse debris with local hummocky topography and longitudinal or arcuate ridges and furrows. They lie on very gentle to steep slopes or valley floors and are bordered by low ridges. They have no cliffs or extensive ledges at their heads. All lack fine interstitial debris and are crudely sorted from coarse to finer downward. Many have, at least locally, a near-vertical alignment of fragments along their margins, an imbricate structure at their toe, or internal swirl structures. Pre-block stream topography tends to be preserved across them, and their definable movement appears to have been only a few yards. They are believed to be residual from successive freezing, thawing, solifluction, and washing of subjacent unconsolidated deposits. They are associated

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with block fields, block slides, and block sheets. One pre-Wisconsin stage and six Wisconsin and Recent stages are recognized.

COMPARISON OF SIEVE AND THIN-SECTION TECHNIQUE FOR SIZE ANALYSIS

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The recognition that grain-size analyses made by measurement in thin sections are not directly comparable with the results of sieve analyses has led to the search for correction factors to bring into agreement the results obtained from the two techniques. This search had been primarily a theoretical analysis of the effect of sectioning and of the effect of number frequency, which most workers considered the major factors contributing to the difference between techniques.

In this study grain-size analyses of three sets of sedimentary rocks totalling 32 samples were performed by thin-section and sieving techniques. The total distributions and the statistics derived from these distributions are compared for the two techniques; distributions of average samples are similarly compared. Conversion factors which will make the results directly comparable are empirically determined. They vary within samples, among samples, and among rock types. Analytically derived correction factors for sectioning and for weight to number frequency fail to bring results of the two techniques into agreement. Based on experimental results it is concluded that there is now no generally applicable correction factor but that empirically derived conversions with statistically determined confidence limits may be used within a single study.

WIDESPREAD OCCURRENCE AND CHARACTER OF PITCHBLENDE IN THE TRIASSIC AND JURASSIC SEDIMENTS OF THE COLORADO PLATEAU

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During the last three years numerous uranium deposits in the sedimentary rocks of the Colorado Plateau have been shown to contain pitchblende. Although this mineral is not restricted to any one formation, most of its occurrences are in the lower Chinle and Shinarump formations (Triassic). There are two principal modes of occurrence of pitchblende, one with sulfides of copper, the other in asphaltic bodies. In both types, association with fossil plants or occurrence in beds rich in organic debris is generally the rule. Fossil plants replaced by pitchblende and sulfides show remarkable preservation of the organic structures. Pitchblende generally replaces cell walls, while the copper sulfides fill the cells, as is shown particularly well at White Canyon, Utah. Under these conditions the hardness and reflectivity of the pitchblende may differ considerably from that of hydrothermal vein pitchblende. At Seven Mile Canyon, Utah, in addition to replacing wood, pitchblende rims quartz and limestone pebbles. The ores of Temple Mountain, Utah, contain pitchblende as minute grains, 1–10 microns in diameter, arranged in ribbon or ellipsoidlike aggregates in asphaltite. It is likely that not all the uranium occurs as pitchblende, but that a portion is combined with the organic matter. The paragenesis of the minerals is complex and somewhat obscure, but formation of the pitchblende contemporaneous with, or shortly followed by, copper sulfides is suggested. In the asphaltite deposits a polymerization by alpha particles of light hydrocarbons may be involved.

STUDIES IN THE SYSTEM MgO-Al_2O_3-SiO_2-H_2O

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As a continuation of earlier hydrothermal studies of the systems MgO-Al_2O_3-H_2O and Al_2O_3-SiO_2-H_2O, the influence of silica and magnesia on these respective ternary systems was studied. Magnesian

serpentine admits about 10 mol. per cent Al_2O_3 into solid solution, thereby raising its temperature of stability at least 15° and changing its habit from tubular to platy. The preparation of various serpentines including nickel serpentine (slightly fibrous) and magnesia-germania serpentine (good hexagonal plates) support the concept that size of ions controls the morphology. Pure aluminous montmorillonite admits magnesia into its structure, giving rise to a large primary-phase volume of quaternary solid solutions. The decomposition temperature of magnesian montmorillonite is greater than that of the pure aluminian end member, attaining a maximum of about 500°C. An "X-phase" is also encountered.

Phase equilibria in the high-alumina corner of the system indicate stability of the corundum-cordierite join above 500°C. and 5000 psi. Apparent disagreement with earlier work in other parts of the system and the effect of the nature of the starting material on the attainment of equilibrium are discussed.

MINERALOGY OF THE RESIDUAL KAOLINS OF THE SOUTHERN APPALACHIANS

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The residual kaolins of the Southern Appalachian region were studied to evaluate conditions giving rise to halloysite and kaolinite.

A new differential thermal-analysis technique was developed to determine quantitatively the relative amounts of endellite versus kaolinite and/or halloysite in a sample. This was used along with other analytical methods to make quantitative mineralogical analyses of the residual clays.

The mineralogical analyses and thin-section studies formed the basis for determining the sequence of weathering in the granites and pegmatites. Halloysite is formed only from the weathering of feldspars, and under conditions of intense leaching is formed from both the plagioclase and potash feldspars. The primary muscovite always alters to vermicular kaolinite. Where leaching is less intense, vermicular kaolinite is formed from the potash feldspars through the intermediate stage of secondary mica of the muscovite type, and halloysite is formed from the plagioclase feldspars. Where acid leaching conditions obtain but are least intense vermicular kaolinite is formed from the weathering of feldspars through the intermediate stage of secondary mica with minor amounts of halloysite forming directly from feldspar. Once secondary mica is formed, vermicular kaolinite is the next weathering product.

PETROGRAPHICAL AND STATISTICAL INVESTIGATION OF DEPOSITION WITHIN A GROUP OF ESKERS IN SOUTHERN MICHIGAN

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Eaton, Ingham, and Livingston counties, Michigan, are traversed by eskers which strike north. Vertical and lateral samples of the material from five prominent eskers were collected, sieved, and separated by bromoform. The sands were investigated by modern petrographic methods in the search for further information on the origin of eskers. The heavy-mineral suites from all eskers showed a distinct correlation. The roundness and sphericity values of the quartz grains were remarkably similar. In each esker there was a notable difference of increasing roundness and decreasing sphericity from north to south. An accurate and rapid method for determining roundness and sphericity values simultaneously was devised. A camera lucida projected the image of the quartz grains upon a concentric-circle protractor which had been drawn on a large piece of white paper. The radius of curvature of each corner and the largest inscribed and smallest circumscribed circles were measured simultaneously by shifting the protractor under the projected image of the grain. This study strongly supports the

theory that these eskers were deposited in subglacial stream channels. The results proved the advantage of statistical data as an aid in correlating glacial land forms.

MISSISSIPPIAN GRAINGER FORMATION IN NORTHEAST TENNESSEE*

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The Grainger formation (early Mississippian) has been traced and mapped in detail in the Greendale syncline northeastward from the type locality in Grainger County, Tennessee, across Hawkins County, Tennessee, to the Tennessee-Virginia line. Four subdivisions are recognized: in ascending order, basal, lower sandstone, middle, and upper sandstone members.

The basal member, 200 to 300 feet thick, changes laterally from fissile gray shale in Grainger County to fossiliferous green siltstone in Doubling Mountain, Hawkins County, and to yellowish silty shale near the Tennessee-Virginia line. The lower sandstone member is composed of 75 to 200 feet of very fine-grained, medium-bedded sandstone that locally includes pebbly layers and fossiliferous beds. The middle member consists predominantly of structureless green fossiliferous siltstone and also includes a few beds of fine-grained sandstone, shale, and fossiliferous glauconitic material. The upper sandstone member, 100–150 feet thick, consists of gray, coarse-grained, cross-bedded, feldspathic sandstone and conglomerate. Fossils from the Grainger formation have not yet been studied in detail but seem to indicate the formation spans at least part of the Kinderhook and probably most of the Osage intervals of the Mississippian standard section.

The Grainger formation of the present writer agrees with the "Grainger shale" of Campbell (1894) and requires that the "Grainger shale" of Keith (1896) be redefined in its type area to exclude the Devonian beds Keith included in the lower part of the "Grainger shale."

EVALUATION OF TECHNIQUES FOR DATING CENOZOIC STRATA IN CALIFORNIA

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In mapping certain late Tertiary formations in central California, we are confronted with the inconsistent dating of stratal units throughout the Pacific Coast Province. Such inconsistency is attributable to the discrepancy between the chronology based on fossil invertebrates and that based on fossil mammals.

The techniques of dating resulting from studies on fossil mammals, invertebrates, and plants must be evaluated and followed according to their typological validity. A most refined provincial chronology, formulated by paleontological criteria, and stated in terms of Lyellian names—*i.e., Miocene, Pliocene*—can evolve only from control based on biologic entities which: (1) are common to the European area and to the province concerned, (2) are characterized by restricted biozones, and (3) are demonstrably rapid in dispersal across the world within time intervals which are insignificant as compared to present subdivisions of the geologic time scale.

Present studies indicate that only the technique of dating which involves use of mammals *approaches* fulfillment of these requirements. Provincial chronologies arranged in terms of the available local Stage-Age names demonstrate the stability and agreement of intraprovincial datings; and, further, avoid untenable delineation of Series-Epoch boundaries by means of local, nontypological data.

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DEPOSITIONAL ENVIRONMENT CHARACTERISTICS ALONG THE GULF COAST. PART 2: EAST MISSISSIPPI DELTA AREA

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On the eastern side of the active Mississippi Delta an area in which rapid sedimentation is occurring is being studied in a manner similar to the Texas region as described by F. P. Shepard. This investigation has not progressed as far as the Texas work, but here also sediments of different environments are recognized. The chief delta-sediment types recognized as constituting traceable units are: (1) marsh deposits, (2) delta-front silts, (3) pro-delta muds, and (4) offshore clays. Recognition of these sedimentary units is based largely on lithologic characteristics. In addition to these strictly deltaic deposits, a large area of sand bottom east of Breton Island and the Chandeleur Arc has been studied. The sand is largely the result of reworking of older deposits and probably averages less than 10 feet thick. In some parts of this area, however, shoaling depths indicate sand deposition due to currents which flow southwest along the eastern side of the Chandeleur Arc. Other units which have been mapped are the deposits which occur between the pro-delta muds and the sand and the heterogeneous mud-sands and muds of Breton Sound.

Inshore the recently deposited deltaic sediments are being laid down on a substrate apparently related to the St. Bernard Subdelta. Farther offshore to the east the substrate is believed to be older and locally may have been subjected to subaerial weathering.

TAZEWELL GLACIAL SUBSTAGE OF WESTERN ILLINOIS AND EASTERN IOWA*

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The Green River lobe of Tazewell ice extended west of the Mississippi River to the eastern border of the Goose Lake Channel in Clinton County, Iowa, and northwestward to within 1½ miles of the village of Goose Lake, Iowa. This lobe, about 13 miles wide, crossed the Mississippi River between North Clinton (Lyons), Iowa, and Princeton, Iowa. The westward extension in Iowa is across an area previously mapped as Iowan and Kansan.

North of the Green River lobe a large, temporary glacial lake (Lake Savanna) was formed in the Mississippi River Valley and its tributaries. Terrace remnants of sands, silts, and clays covered by loess record the existence of this lake. Their heights are in accord with the height of the Goose Lake Channel outlet 14 miles northwest of Clinton, Iowa.

When the Tazewell ice reached the "Big Bend" of the Illinois River it blocked the former Mississippi River drainage from Clinton, Iowa, to Bureau, Illinois, and diverted the waters to the present course of the Mississippi from and including the Cordova gorge to the present mouth of the Illinois River (old Mississippi).

PROBLEM OF TRACE-ELEMENT DISTRIBUTION IN MAGMATIC MINERALS

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Goldschmidt and his associates showed that the distribution of trace elements in magmatic minerals depends on the camouflage principle, whereby a minor element replaces a major element of similar size. It was also claimed that where there is a difference in size the larger element (cation) is concentrated in later fractions of the mineral. Evidence presented shows that this latter statement is not a general rule and has no theoretical or experimental basis. Camouflage may also occur where there is a valency difference, but again it cannot be predicted from valency and size alone, whether the minor element is concentrated or dispersed during magmatic crystallization.

* Studies made under the auspices of Illinois State Geological Survey and Iowa Geological Survey.

Theory shows that where a minor element—*e.g.*, Tl^{+1}—replaces K^{+1} in the potash feldspars (continuous solid solutions assumed), then the M.P. of the hypothetical feldspar $TlAlSi_3O_8$ determines whether thallium is enriched or impoverished during crystallization. Melting points have no direct relation to ionic size. Collected data on the M.P.'s of end members in binary solid-solution series confirm that there is no regular relation between M.P. and ionic size or charge of the cation. If conditions are assumed to be more complex than the simple binary solid solutions, ionic size and charge matter even less. Wickman's activation energies are of little assistance, because they are closely related to lattice energies, which do not determine melting points.

The camouflage, capture, and admission principles were established on the basis of spectrographic data on minor-element abundances. Review of the more recent literature shows again that these principles are incapable of general application. Where they seem to apply (*e.g.*, Li and Mg, Tl and K) this must be regarded as coincidental. Thus, it is impossible to predict, from ionic properties alone, the behavior of a minor element during magmatic evolution, beyond indicating generally where it will be camouflaged.

DEPOSITIONAL ENVIRONMENT CHARACTERISTICS ALONG THE GULF COAST. PART 1: PROJECT DESCRIPTION AND ROCKPORT, TEXAS, AREA

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An extensive program of recent sediment studies sponsored by the American Petroleum Institute is being conducted by members of the Scripps Institution staff with the active collaboration of many scientists. Approximately 8 months of field work has been conducted in an area along the Texas coast and along the east side of the Mississippi Delta. Large suites of samples have been collected from the deltas, shallow bays, barrier islands, and shoal portions of the open Gulf. Virtually all aspects of the sediments are being studied along with the ecology of the organisms. Special investigations are being conducted under the following general guidance: grain size distribution—D. L. Inman; petrography—M. N. Bramlette; clay mineral studies—R. E. Grim; general chemistry—G. Bien; chemistry of suspended particles—U. G. Whitehouse; macro-organisms—J. W. Durham; Foraminifera—F. B Phleger; Ostracoda—F. M. Swain; microbiology—Carl Oppenheimer; and pollen analyses—L. R. Wilson.

The studies of sediments from the Rockport, Texas, area indicate natural subdivisions as follows:

1. An upper bay facies—poorly sorted clays partly laminated and with a brackish fauna.
2. A lower bay facies—poorly sorted mud-sand, lacking lamination, having confused stratification and a fauna that is an admixture of brackish and open Gulf. Coprolites abound, and glauconite is rare.
3. A barrier-island facies—predominantly well sorted sand but varying from a high degree of sorting along the outer beaches to a muddy sand in the flats and lakes bordering the bays.
4. An open Gulf facies—dominantly silt except for the sand zones near the shore. Glauconite is an important constituent, and coprolites are rare. The faunas are distinctive from those of the bays.

STRUCTURAL GEOLOGY OF THE WILMINGTON, VERMONT, AREA

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The Wilmington area of southern Vermont is on the eastern flank of the Green Mountain anticlinorium. The stratigraphic sequence comprises Precambrian gneisses and metamorphosed Lower Paleozoic clastic sediments and volcanic rocks. These are separated from the Precambrian gneisses by an angular unconformity.

The rocks of the eastern flank of the anticlinorium form an easterly dipping homoclinal sequence locally complicated by small anticlines and larger domes. The domes are 4–8 miles long and have many structural features similar to those described by Eskola and others. They are found about 9 miles east of the outcropping Precambrian unconformity.

Minor structures studied include minor folds, fold lineation, mineral and pebble orientation and lineation, quartz rodding, boudinage, and cleavage. Most minor structures of the domes have attitudes which are the reverse of those in the anticlines. The minor folds of the domes have a shear sense, which indicates that the upper beds have moved relatively toward the axis of the syncline. Boudinage as well as mineral and pebble lineation, is oriented normal to the attitude in the anticlines.

The study of minor structures in that part of the anticlinorium within the area indicates that it was formed by lateral compression. Minor structures of the domes, on the other hand, suggest that they are produced by vertical movements of the core gneisses relative to the overlying schists.

TECTONIC ELEMENTS IN SPACE AND TIME

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In recent papers the tectonic behavior of any locality is postulated to be governed by the stage in the tectonic cycle achieved at the time of reference. Furthermore, the treatment supposes that the observed stage has been preceded by a recognizable earlier stage and will be succeeded by a predictable later one.

The writers recognize that geosynclines (and other tectonic elements) emerge, function, and disappear, and thus follow a cycle of a sort. However, intensive studies of large continental areas and their structural and stratigraphic patterns have made it clear that there are fundamental differences in the tectonic behavior of various parts of the earth's crust and that these differences do not necessarily follow one another cyclically. The writers believe the major factors in tectonic behavior of any area, and its attendant structures, geomorphology, and sedimentation, are functions of geographic position within a tectonic framework, rather than of position in a cycle.

Regional structural and stratigraphic investigations of selected areas, which include eugeosynclines, their cratonic margins, and adjacent parts of the stable craton, indicate a lack of a predictable sequence of events within the eugeosynclines, and emphasize the basic distinctions between eugeosynclinal behavior and the tectonism displayed by all elements of the craton, including the so-called miogeosyncline.

ORIGIN OF THE CHROMITE DEPOSITS OF THE BAY OF ISLANDS IGNEOUS COMPLEX, NEWFOUNDLAND*

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The Bay of Islands complex forms a discontinuous belt of layered ultrabasic and gabbroic rocks along the west coast of Newfoundland. The basal ultrabasic zones of the plutons, which are as much as 4 miles thick, are composed of undifferentiated enstatite and forsterite. These zones are overlain by banded gabbroic rocks. The two rock types are interbanded at their contacts and are parts of the same intrusion.

Chromite deposits occur near the top of the ultrabasic zone, below the ultrabasic-gabbro contact. Coarse-grained pyroxenite (diopside? or enstatite?) is found near the chromite horizon and nowhere else in the ultrabasic zone. Feldspar (now hydrogrossular) is found in the ultrabasic rocks near the chromite deposits. In the interbanded gabbroic and ultrabasic zone, spinel in places forms rims

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around anorthositic lenses in feldspathic dunite. These rims appear to be the result of reaction between ultrabasic and feldspathic materials. It appears that the presence of lime and alumina is favorable to the concentration of chromite into a chromite mineral deposit.

The formation of spinel by the interaction of olivine and anorthite has been proven experimentally by Anderson (1915), and the subsequent conversion of spinel to chromite has been described by Bowen (1928). It is concluded that this reaction explains the localization of chromite deposits near the top of the ultrabasic zone below the overlying banded gabbroic rocks. At the same time, the reaction of lime with the ultrabasic magma has caused the formation of the *diopside* bands found near the chromite deposits.

A similar relation of chromite deposits to gabbro contacts is found in the Bird River sill of Manitoba and in the Camagüey complex of Cuba. This relation may be more common than previously suspected and, where found, is a valuable guide to prospecting.

SLOPE ANALYSIS OF BADLANDS TOPOGRAPHY

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In the White River Badlands of South Dakota, differences are apparent between the topography developed in areas underlain by the Brule formation and that in areas underlain by the Chadron formation. The mean maximum angle of slope for typical Chadron topography is 26.2°, with estimated standard deviation of 4.2°, as determined by frequency distribution of a field sample of 90 slope readings. In the Brule formation mean maximum slope angles of 56°, 49.5°, and 51° were obtained from samples of 18 to 78 readings taken in three areas. Standard deviations were 4.8°, 5.7°, and 6° respectively. A "t" test of differences between means of Brule and Chadron slope samples yielded a probability of less than 0.001, meaning that the observed differences would be expected to occur by chance variations in sampling less than one time in 1000, and therefore that the differences are significant.

Each slope mean is interpreted as representing an equilibrium condition in which the slope has been adjusted to achieve a steady state between the resistivity of the material to erosion and the intensity of erosional processes tending to reduce the slope angle. The Chadron formation consists chiefly of spongey clays and silts, which tend to flow readily when saturated, forming low, rounded hills. The Brule formation, by contrast, consists of massive clays and nodular clays, lenticular sandstones, and dense ash beds, which form steeper slopes because they offer greater resistance to run-off erosion and are less susceptible to flowage when wet.

LEAD-URANIUM AGES OF SOME URANINITES FROM TRIASSIC AND JURASSIC SEDIMENTARY ROCKS OF THE COLORADO PLATEAU

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During a study on the origin of the uranium deposits in the Triassic and Jurassic sedimentary rocks of the Colorado Plateau, 13 samples of uraninite from 9 deposits were collected for Pb^{206}/U^{238} and Pb^{207}/U^{235} age determinations. These uraninites are believed to be the most reliable of more than 100 samples from the Plateau on which age determinations have been made. The 13 uraninites have a mean Pb^{206}/U^{238} age of approximately 70 million years when corrected only for common lead.

Chemical and mass spectrometric errors change the mean Pb^{206}/U^{238} age by approximately ± 4 million years. Uncertainties resulting from the correction for common lead and from the possible presence of old radiogenic lead in the ores will decrease the mean Pb^{206}/U^{238} age by approximately 3 million years. Corrections for the selective loss of uranium will decrease the mean Pb^{206}/U^{238} age, whereas selective loss of daughter products will increase the mean Pb^{206}/U^{238} age by approximately 10 million years.

Holmes gives 130 and 160 million years as the close of the Jurassic and Triassic periods, respectively. If the ages calculated for the samples of uraninite are close to the true ages of the ores, then the uranium was introduced into the sedimentary rocks in late Mesozoic or early Tertiary time (60 to 70 million years ago). This conclusion differs markedly from conclusions based on other evidence that the uranium ores were formed in the Triassic and Jurassic sedimentary rocks of the Colorado Plateau during or soon after the deposition of the rocks.

PORPHYRY INTRUSIONS IN THE BEARTOOTH RANGE, NEAR RED LODGE, MONTANA

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Porphyry intrusions are exposed for a vertical distance of about 4000 feet, at approximate elevations between 6000 and 10,000 feet along the Red Lodge Cooke City Highway into Yellowstone Park. As it is unusual to find such fresh and deeply cut exposures, the present study aims to determine whether mineral or textural change occurs with depth. This may aid in understanding the method of intrusion or the relationship of the porphyry to the cover rock.

The porphyries form sheets or sills, ranging from 50 to several hundred feet thick. Their attitude ranges from almost horizontal to about 30-degree dip. Jointing is pronounced. Faulting occurred within the sheets, and some contacts with Precambrian rocks are faults marked by gouge and mylonite zones.

The rock is quartz monzonite. The fine-grained groundmass is either brown, gray, or light gray with phenocrysts of feldspar (abundant), quartz, and hornblende. In the limited section studied along the highway and on Line Creek Plateau, the porphyries are in contact with Precambrian granites, gneisses, and amphibolites. The field survey shows no mineral or textural change in the rock with depth. A petrographic examination in progress will determine whether a variation occurs. The work also will be extended to porphyry bodies which have intruded sediments near by.

The porphyries examined are post-Precambrian. Similar porphyries in associated areas, which have intruded sediments, have been dated as late Cretaceous or very early Tertiary.

PALEOZOIC POSITIVE AREA IN NORTHWESTERN UTAH

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The site of the Raft River range in northwestern Utah and adjacent parts of Idaho and Nevada had pronounced positive tendencies during the Paleozoic. This area is shown on current paleogeographical maps as being near the center of the Paleozoic Cordilleran geosyncline with a record of submergence and sedimentation for all Paleozoic periods. Reconnaissance shows the sedimentary section to be relatively thin with probably only Cambrian and Pennsylvanian systems present.

Above the Precambrian granitic rocks is what appears to be a regional erosional unconformity. Upon this lies slightly metamorphosed sedimentary rocks having at the base dense, vitreous quartzite, followed by sericitic schists and, at the top, moderately altered dolomite and limestone, the whole quartzite-phyllite-carbonate section ranging from a few feet to about 2500 feet in thickness. Above the metamorphic series and separated from it by a basal quartzitic conglomerate or sandstone is a series of unmetamorphosed limestones and silty limestones estimated to be up to 3000 feet thick. About 1000 feet from the base fusulines were collected which have been determined as *Waeringella* of probable Virgil age. No fossils have been found in the metamorphic rocks, but lithology and position suggest Cambrian age.

This uplift greatly narrows the Rocky Mountain miogeosyncline, provides a source for sediments, and is important tectonically.

MAPPING AND STATISTICAL ANALYSIS OF GROUND SURFACE SLOPE

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Within fluvial drainage basins rates of runoff, soil creep, and soil flowage are functions of ground surface slope. Slope maps show (1) degree of slope or (2) magnitude of the downslope component of gravitational acceleration. The first type of map uses lines of equal slope tangent (isoclines or isotangents) and is therefore a form of first-derivative map. Isoclines are drawn from a large number of slope readings determined from a reliable large-scale contour map or by direct field measurement. Planimeter measurement of areas between successive isoclines yields a percentage frequency distribution from which mean slope and standard deviation are computed.

The second type of map uses lines of equal sine of slope (isosines) and thus shows the distribution of the downslope component of gravitational acceleration, which determines the intensity of shear stresses acting upon soil and surface water. Measurement of areas between successive isoclines yields a frequency distribution from which mean and standard deviation of gravitational acceleration are computed. Statistically similar data are obtained more rapidly by random sampling of slope sines.

Frequency-distribution histograms of area with respect to tangent and sine of slope angle show the influence of stage of development of the landmass and structure of underlying rock. Distributions are symmetrical with low dispersions in areas of mature topography and smooth, straight slopes, whereas in youthful areas or in those that have strong structural benching of slopes the distributions are strongly skewed or bimodal and have large dispersions.

INFLUENCE OF GEOLOGICAL CONDITIONS ON UPLIFT ASSUMPTIONS FOR LARGE DAMS

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Uplift pressures at the base of a dam and in the foundation influence the sliding factor and the stability against overturning. The designer recognizes these facts and has established uplift assumptions which are generally used regardless of geological conditions.

The type, structure, condition, and topography of the foundation rock influences the extent of uplift under a dam. In sedimentary rock where impervious beds are interbedded with open, pervious beds, the situation may be either favorable or detrimental to the relief of uplift pressures. If the strata dip upstream and the dam is founded on open free-draining rock and an impervious bed is located at the proper depth below the foundation, a tight grout curtain near the heel of the dam and tied into the impervious bed will cut off the reservoir head so only the uplift from the tailwater is effective. In contrast where the beds dip downstream an impervious stratum near the foundation may trap the head of the reservoir so that about 100 per cent uplift occurs under the structure.

In the lower reaches of the Columbia River the basalt flow contacts and fractured rock, along with deep slots and potholes in the river bed, provide natural relief for uplift pressures.

In massive tight rock the determination of uplift assumptions is more difficult as the artificial drainage provided cannot be accurately evaluated.

Proper consideration of the geological conditions at each project should result in the use of safe and economical uplift assumptions.

REVISION OF THE DEVONIAN TRILOBITE SPECIES *PROETUS CRASSIMARGINATUS* HALL

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The lower Middle Devonian trilobite species *Proetus crassimarginatus* was first described and illustrated by James Hall in 1843 on the basis of a pygidium found in lower Onondaga strata

near Williamsville, New York. Hall (1876) and Hall and Clarke (1888) illustrated hypotypes assigned to this species consisting of glabellae, free cheeks, and pygidia from the Onondaga limestone of western New York and southwestern Ontario, the Columbus limestone of Ohio, and the Jeffersonville limestone of southern Indiana and northern Kentucky. These hypotypes are composites of three species of which two can be referred to the genus *Proetus* and the third to the genus *Dechenella*. A study of the specimens previously described from the type locality and of additional specimens recently obtained from this region has resulted in a redescription of *Proetus crassimarginatus* and in the rejection of the majority of the hypotypes assigned to the species.

ENGINEERING GEOLOGY OF THE CHESAPEAKE BAY BRIDGE

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The $45,000,000 structure, dedicated July 30, 1952, extends 4.3 miles across Chesapeake Bay, linking Maryland's Western Shore with Delmarva Peninsula. Superstructure consists of simple and cantilever deck spans, 2920 feet suspension main bridge, and 1720 feet through cantilever span. Substructure is entirely on steel piles up to 135 feet long and penetrating to lowest elevation −203 feet M.S.L.

Two alternate locations were investigated by 38 borings, totalling 7372 linear feet, the deepest reaching elevation −355 feet. Representative grain-size analyses, time-consolidation, Atterburg Limit, compression, and related laboratory tests on 501 ordinary and 93 undisturbed samples furnished quantitative data for substructure design. To enable three-shift drilling, and eliminate shore-based survey crews and delays during periods of restricted low-level visibility, barges were positioned by use of special sextant charts which afforded virtually instantaneous graphical fixes based on observed angles between night-lighted, elevated shore signals.

Two shore-to-shore geologic sections were developed, depicting unconsolidated Coastal Plain formations penetrated, including recent and Pleistocene silts, sands, and gravels; the Aquia (Eocene); and the Monmouth, Matawan, and Magothy (Upper Cretaceous). Explorations of the drowned Pliocene (?) valley of the Susquehanna, encountered 1.5 miles west of the Eastern Shore beneath 65–90 feet of water, were of critical engineering importance and are of unique geologic interest. Former channel, approaching 5000 feet in width, bottom at elevation −170, and filled with up to 100 feet of highly compressible organic silt, necessitated use of longest piles on project.

Integrated geologic and soils studies proved exceptionally valuable in all phases of the project.

CAUSES AND PALEOECOLOGICAL SIGNIFICANCE OF DWARFED FOSSIL MARINE INVERTEBRATES

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A "typical" dwarfed assemblage, the limonitic Pennsylvanian "Dry shale fauna," was studied. Approximately 4000 specimens were collected in Lyon, Greenwood, and Elk counties of Kansas in gray argillaceous shales. Limonitic fossils occur above the coal in Elk County. Restricted environment and catastrophic death are postulated.

All specimens were measured and tallied on the Wentworth scale permitting an effective size-grade analysis. The major grade size was thus determined. Juveniles and adults were distinguished by morphologic criteria, graphic analysis, and use of the known upper size limit for any given genus or species.

Adult imitoceratids appear to be true dwarfs; all other elements consist of immature forms and/or undwarfed adults. The assemblage is termed a "pebble necrocoenosis" (8-4 mm.) indicating that sedimentary processes (sorting) and not biological processes (growth retardation) have led to the

observed size uniformity. A critique of the literature (Salem, Tully, Maquoketa, etc.) extends application of this distinction to similar assemblages.

Biological evidence and theories on growth in marine invertebrates are applied to the paleontological problem of dwarfing. The evidence includes: experimental growth acceleration (diatoms) by previously frozen water and the independently observed latitudinal size increase in marine invertebrates; experimentally controlled size variation with changing salinity, etc.; explanation of growth-retarding effects of iron and *oligodynamik* waters; *Pufferwirkung* to explain normal-sized pyritized faunas; physiological effects of phosphates; influence on cell growth of the sulfhydryl group.

Suppression of terms "dwarf," "depauperate," "diminutive," to designate small size of a fauna is proposed. Pebble necrocoenosis (psephonecrocoenosis) is the suggested substitute.

IRON-ORE DEPOSITS OF LIBERIA

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Geologic investigations in Liberia from 1944 to 1952 have revealed two distinct types of bedrock iron deposits: (1) low-grade itabirite, and (2) replacement bodies of medium- to high-grade ore.

Well-layered itabirite consisting mainly of quartz combined with magnetite or hematite or both, and averaging 30 to 40 per cent Fe, is widely distributed in Liberia. Large masses several miles long and many hundreds of feet thick form or cap the highest mountains in the country. The itabirite ranges from fine-grained ferruginous slate to well-crystallized granular rock containing magnetite grains up to a quarter of an inch across. Bedded quartzite is associated with the itabirite in two major deposits, leaving little doubt as to their sedimentary origin.

All high-grade ore is associated with folds in medium- to coarse-grained itabirite. Although the itabirite has been locally hydrothermally enriched in many steeply dipping homoclinal masses, all known major high-grade ore bodies are related to crests or troughs of folds. The large ore bodies in Bomi Hill are believed to have been formed mainly by replacement of itabirite lenses and to a lesser extent by replacement of quartz-plagioclase-mica-garnet gneisses, with which the itabirite is interlayered in a relatively open irregular basin. The main iron mineralization was preceded or accompanied by formation of skarn rich in cummingtonite and anthophyllite, epidote, hornblende, and dark mica, with accessory pyroxene and spinel, all of which have been extensively altered to chlorite and serpentine minerals. Layered ores of good milling grade include recrystallized itabirite, itabirite in which quartz has been replaced mainly by cummingtonite, and magnetite-cummingtonite-quartz rocks formed by replacement of gneiss along closely spaced shear planes.

BASIN AND RANGE STRUCTURE SOUTH OF RENO, NEVADA

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The late Cenozoic structure in the Mount Rose and Virginia City quadrangles, south of Reno, Nevada, involves much warping, in addition to normal faulting. The eastern front of the Carson Range of the Sierra Nevada in this region is in part an eroded complex fault scarp, but it changes northward into a great fold. Much of the structural relief of the Virginia Range is also the result of a combination of warping and faulting rather than of faulting alone. Steamboat Hills, in the basin between the Carson Range and the Virginia Range, is a crude dome rather than a simple up-faulted block. Warping and tilting imply crustal shortening in a horizontal direction, as opposed to normal faulting, which implies crustal elongation. The structure of the area south of Reno is consistent with a hypothesis that shortening and elongation are approximately balanced; regional extension or compression need not be postulated.

Cenozoic intrusions and volcanic vents seem generally to occupy the structurally high areas and seem to be generally lacking in structurally low areas. This relationship suggests cause and effect between igneous activity and structural movements. Uplifting of the ranges relative to the basins by intrusions of magma might explain the structure, independent of regional compression or extension.

FAULTS AND GAPS IN THE PALISADE RANGE, ROCKLAND COUNTY, NEW YORK

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At a number of places along the river front of the Palisade Range in Rockland County the base of the diabase sill is vertically offset, minimum amounts being 400 feet at Short Clove, 200 feet at Long Clove, 40 feet at Trough Hollow, 40 feet at Rockland Lake landing, 200 feet at North Nyack, and several displacements in Sparkill Gap ranging up to 200 feet. These offsets represent either faults or crosscuts of the sediments by the diabase. Though talus and till impede observation, evidence shows that most, if not all, are fault displacements. The columnar joints, which stand normal to the base of the sill, show no evidence of abrupt flexing of that base. The trap and underlying sediments, where exposed at these sites, are shattered. At some sites, slickensides and fault striae are seen. And the topographic evidence—that is, the fact that each of these offsets coincides with a deep notch in the range—is very striking.

Differential weathering and erosion along these faults might readily explain the jagged crest of the Palisades in New York as contrasted with the smoother crest in New Jersey, where few faults occur. Also, the broad gap at Sparkill is reasonably explained by the fact that at least four faults break the range there

GEOLOGICAL CONSIDERATIONS IN DESIGN OF PANAMA CANAL EXCAVATION SLOPES

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Geologic and soil-mechanics studies performed in the Panama Canal Zone in connection with the Third Locks project and under Isthmian Canal Studies—1947 have largely been concerned with design of excavation slopes that would be secure from major slides. These investigations included extensive sampling and laboratory testing as well as an evaluation of factors that influenced slide development during original Canal construction, and since.

Formations that would be involved in construction of a sea-level canal at Panama are heterogeneous and range from pre-Tertiary to Pleistocene. The region traversed by the preferred alignment is structurally complex, and the strength of formations is extremely variable.

In addition to determining distribution, structural relationship, and the physical properties of materials that would be involved in future Canal construction, the studies have permitted preliminary design of stable slopes for all important rock units. For certain formations, characterized by low shear strength, data as to proper slope for varying depths of excavation have been presented as curves upon which the height of cut is plotted against cotangent of slope. Cuts through rock of high shear resistance were designed on the basis of minimum excavation quantity commensurate with navigation and construction facility, and safety from rock falls.

As a result of analyses, it has been concluded that major slides can be prevented by initially cutting the banks to predetermined slopes established by engineering geology and soil-mechanics investigational and design procedures.

INTRUSION BRECCIAS OF MAJUBA HILL, NEVADA

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Majuba Hill, in the Antelope Range, Pershing County, Nevada, is a complex, roughly ellipitical plug with a maximum diameter of 5000 feet. Shale, limestone, and sandstone of Triassic (?) age was first invaded by Tertiary (?) dikes and sills of andesite, dacite, latite, and diorite, and later by the plug of rhyolite porphyry, quartz porphyry, and porphyritic rhyolite.

Dikes and irregular bodies of breccias cut all rocks within the plug, except the porphyritic rhyolite, and cut the metamorphosed shales along the borders. More than 20 lithologic types of intrusion breccias are recognized. Rhyolite porphyry, quartz porphyry, or a mixture of quartz and tourmaline commonly forms the groundmass of the breccias; and copper, tin, and uranium minerals occur in the intrusion breccias that contain a matrix of quartz and tourmaline.

The intrusion breccias are believed to have been formed by: (1) incorporation and incomplete assimilation along the edges of rhyolite porphyry and quartz porphyry dikes, (2) autobrecciation of rhyolite porphyry and quartz porphyry dikes and masses as they were injected into the plug, and (3) minor explosive action resulting from the rapid release of gases emanating from the magma.

MASS SPECTROMETRIC DETERMINATION OF THORIUM

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Thorium possessing a Th^{230} to Th^{232} ratio of four has been isolated in milligram amounts from a Colorado Plateau uranium ore. This carrier has been used in conjunction with a mass spectrometer equipped with an electron multiplier which permitted isotopic analysis of amounts of thorium as low as 1 microgram. Under these conditions it was possible to determine 0.01 microgram of thorium with an accuracy of $\pm 10\%$ and amounts of 0.1 microgram or more to $\pm 1\%$.

The method has been applied to zircon in a granite from the Haliburton Area of the Canadian Shield. Three analyses of separate powder fractions gave results of 2012, 2033, and 2058 parts per million of thorium with an analytical error of $\pm 1\%$ for each determination.

On the basis of previously determined uranium and lead data the age of the mineral is believed to be 1050 $\pm$ 20 million years. The newly calculated thorium-lead age is 420 $\pm$ 10 million years. A sufficient number of uranium, thorium, and lead analyses have been made to establish that the sampling was representative. Since the zircon has metamict and unaltered zones the data may be explained by an accumulation of thorium relative to uranium in the metamict phase, which could allow Pb^{208} to be lost more easily than Pb^{206} or Pb^{207}. Further investigation of the problem is under way.

THERMAL TRANSFORMATIONS IN SOME LAYER SILICATE MINERALS

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Single crystals of muscovite, biotite, and chlorite and sedimented flakes of illite were subjected to progressive, stepwise heat treatment by two methods: (1) conventional air-quench procedure, and (2) high-temperature method with furnace mounted on an x-ray spectrometer. Comparisons of the x-ray data indicate marked differences in the high-temperature region (800°–1100°C) depending on variations in experimental procedure, particle size, and perhaps other factors. The high-temperature furnace procedure is the more rapid and accurate method.

Visual images of the structure (electron density along *c* axis) were calculated by Fourier syntheses. The close relationship between the specific layer structure, the amount of dehydration, the gradation (or lack of it) to an anhydride, and the early appearance of new phases were observed.

Precise evaluation of thermal transformations requires careful consideration of the time factor with respect to particle size and degree of crystallinity, approach to equilibrium, and decomposition temperature.

UPPERMOST CRETACEOUS AND PALEOCENE NONMARINE MOLLUSCAN FAUNAS OF SOUTHWESTERN ALBERTA

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In southwestern Alberta the Bearpaw shale is overlain, in ascending order, by the nonmarine Blood Reserve, St. Mary River, Willow Creek, and Porcupine Hills formations, cumulatively over 10,000 feet thick.

Brackish-water mollusks, of little stratigraphic significance, are abundant in the Blood Reserve and the basal part of the St. Mary River formation. In the succeeding strata three distinctive faunas, of fresh-water and terrestrial mollusks including the following genera: *Fusconaia* ?, *Plesielliptio*, *Sphaerium*, *Pisidium*, *Viviparus*, *Campeloma*, *Lioplacodes*, *Scalea*, *Goniobasis*, *Hydrobia*, *Valvata*, *Ferrissia*, *Pleurolimnaea*, *Oreohelix*, *Polygyra*, *Urocoptis*, *Pseudocolumna* and *Grangerella*, are developed. The fauna of the St. Mary River formation (30 species, 6 new, 15 undoubtedly do not occur in the overlying Paleocene assemblage) may be considered pre-Lance, as equivalents of the Whitemud and Battle formations occur at the top. The Willow Creek formation contains two faunas: the lower (20 species, 2 new, 18 of which occur in the underlying fauna) is regarded as representative of the Lance stage as dinosaur bones are associated; the upper fauna (23 species, 1 new), also present in the Porcupine Hills formation, comprises Fort Union (Paleocene) aquatic species and terrestrial gastropods of the Paleocene ("upper Saunders") of west-central Alberta.

Paleontological evidence now permits the recognition of Cretaceous and Paleocene equivalents within the Willow Creek formation; in the southern part of the area no stratigraphic break accompanies the faunal change; farther north the Edmonton-Paskapoo unconformity intervenes between partial equivalents of the strata enclosing the two faunas.

PETROGRAPHIC ANALYSIS OF A COLUMN SAMPLE AND OF RUN-OF-MINE LIGNITE FROM ZAP, MERCER COUNTY, NORTH DAKOTA

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Microscopic analysis of North Dakota lignite for anthraxylon, opaque and translucent attritus, fusain, and mineral matter yields information of potential importance to mining and utilization of this coal. Methods of analysis which employ macroscopic examination of surfaces of coal are relatively useless for this reactive substance. Paleobotanical information is especially valuable for lignitic coal and should be used to expand the knowledge gained from purely petrographic studies.

A series of thin sections of a 10-foot column from Dakota Collieries Mine, Zap (Fort Union Formation), was studied. There is a marked concentration of opaque attritus in the upper 4.5 feet. Analysis of a series of thin sections made from a carefully selected representative sample of lumps of stoker size run-of-mine lignite from the mine gave results very close to the overall percentages for the column.

A method for analysis of samples of small particles of lignite was devised in which a crushed representative sample of lignite is embedded in plaster, thin sections made with the usual polishing techniques, and these sections then studied in the same manner as those from a column. This method makes possible petrographic study of a representative portion of a crushed sample prepared for

chemical analysis. Analysis of such a representative sample of run-of-mine coal is more meaningful to utilizers of the mined coal than are analyses of column or core samples, though these are necessay to establish the distribution of constituents within the bed.

SIGNIFICANCE OF THE VARIATION IN NORMATIVE VS. MODAL FELDSPAR OF GRANITES

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Granites having identical normative amounts of "Plagioclase" and "orthoclase" may contain equivalent quantities of these constituents, or they may consist of "one" feldspar (perthite) and quartz. Modal analyses of a series of specimens collected along the contacts of Tertiary granites from the Island of Skye, Scotland, show a variation in modal plagioclase from 0 to 20 per cent. Chemical analyses of the granites indicate that the normative feldspar composition is approximately 30 per cent "plagioclase" and 30 per cent "orthoclase". Such variations in modal feldspar suggest (1) that the granites crystallized at different temperatures, or (2) that the plagioclase ummixed from the potash-bearing feldspar subsequent to primary crystallization. Evidence is presented for and against each of these possibilities.

KAME TERRACES AND KAME PLAINS IN SOUTHEASTERN NEW HAMPSHIRE

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Along the coastal region of New Hampshire, numerous Pleistocene deposits of stratified drift were mapped as kame terraces and kame plains. Beds, of poorly sorted cross-laminated sand and gravel, showing cut-and-fill relationships, show in numerous pits. Despite slumping, it is possible to recognize irregular ice-contact slopes along their edges.

The kame terraces are built against drumlins, kames, and higher kame terraces. Some form complete rings around drumlins. In Stratham, New Hampshire, the kame terraces average 2 to 3 miles long, have smooth tops, and rise 20 to 40 feet above the surrounding areas.

The kame plains, earlier interpreted as crevasse fillings and as moraines, are typically elongate with smooth southeastward-sloping tops. Ice-contact slopes are found on both sides.

Both types have been interpreted as being built against thin blocks of ice by ice-marginal streams, in ice-dammed lakes, and in open holes between ice blocks. Initially some topographic obstruction, such as a drumlin or a bedrock hill, caused the ice to melt producing a hole into which superglacial debris was swept. The streams deposited debris between the ice and the hillsides or between blocks of ice. The internal structure and topographic forms of these features indicate that they grew wider and longer as the retaining ice walls melted back, and stopped growing when the ice was too low or too fissured to hold in the water.

IMPROVED HYDROTHERMAL QUENCHING APPARATUS

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There is increasing interest in the study of the role of volatiles in petrological problems. The high cost of the necessary apparatus has restricted such studies. A simplified design of the hydrothermal quenching apparatus initially developed by O. F. Tuttle reduces this cost manyfold. The apparatus can be built by a novice using only a drill press, saw, and light lathe. All of the materials are available commercially.

The pressure is retained at the principal union in the highest temperature zone by a cone-in-cone seal held together by a weighted cantilever. The temperature is attained by a multiple-unit, split furnace. A rapid quench is obtained by an air blast directed at all sides of the pressure vessel. The working range remains 30,000 psi. and 1000° C. Water, carbon dioxide, and oil have been used successfully as pressure mediums.

The small size, low cost, simple construction, and ease of operation of this apparatus should promote the experimental investigation of the role of volatiles in petrological problems.

PRE-BENTON CRETACEOUS STRATIGRAPHY IN EASTERN COLORADO*

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In eastern Colorado conflicting terminologies are applied to Cretaceous strata between the Jurassic Morrison formation and the Upper Cretaceous Benton shale. Stratigraphic studies reveal that none of these terminologies conform precisely to the principal lithogenetic units and stratigraphic breaks in the sequence.

In their gross characteristics the pre-Benton Cretaceous rocks comprise two lithologically distinct parts, the lower of which exhibits a lenticularity that contrasts with the regularity of succession and lateral continuity of beds characteristic of the upper part. The lower part consists of light-gray, locally conglomeratic sandstone interbedded with variegated claystone. The upper part consists of dark-gray shale that locally contains brown-weathering sandstone units and is capped by a persistent sandstone of similar character. A sharp disconformity—the most pronounced stratigraphic break in the sequence of beds between the Morrison formation and Benton shale—separates these two parts.

The lower part is regarded as a formation lithogenetically more closely related to the Morrison formation, on which it rests with local unconformity, than to the overlying beds.

In the upper part of the sequence the upper persistent sandstone and the shale with local sandstone units are considered distinct, though closely related, formations. Local facies of the shaly formation represent marine, estuarine, and delta-plain environments of deposition.

Of the existing terminologies, only that used in the Arkansas Valley area is adaptable to the tripartite division recognized. It is emended and applied to pre-Benton Cretaceous strata throughout eastern Colorado.

PETROLOGY OF THE JUDITH MOUNTAINS, MONTANA

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The Judith Mountains are a group of Tertiary porphyry stocks and related intrusives that have domed and cut a thick series of sedimentary rocks ranging from Cambrian to Upper Cretaceous. Quartz monzonite intrusions mark the beginning of intrusive activity and form the major stocks in all parts of the mountains. Later igneous rocks represent two lines of descent: (1) more siliceous types exemplified by rhyolite, (2) rocks relatively poor in silica and high in the alkalies, best exemplified by tinguaite. The youngest rock in the area, the alkali granite porphyry of Judith Peak, is rich in both silica and the alkalies and is believed to represent a union of the two separate lineages.

The area is bisected by a strong but irregular east-west fault that divides the mountains into two structural units, each with a distinct assemblage of igneous rocks. The southern unit is characterized by calc-alkaline rocks containing perhaps 50 per cent of highly siliceous rocks—*i.e.*, the rhyloites. The northern unit is characterized by both calc-alkaline and alkaline rocks. Probably less than 1 per cent of the calc-alkaline rocks is rich in silica.

Pre-intrusive structural and erosional events have influenced the mechanism of emplacement of

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* Publication authorized by the Director, U. S. Geological Survey.

the initial quartz monzonite intrusions. Detailed mapping shows large-scale magmatic stoping of the Madison limestone north of the strong east-west fault but not south of it. This suggests that limestone syntexis has desilicated the magma at depth to yield tinguaites, according to Daly's hypothesis. The alkali granite is believed to represent a late siliceous differentiate of the calc-alkaline series, contaminated by alkaline fluids generated by resurgent carbon dioxide released from the assimilated limestone.

GEOGRAPHIC AND STRATIGRAPHIC DISTRIBUTION OF PENNSYLVANIAN COAL IN THE UNITED STATES

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Pennsylvanian coals are restricted to areas east of the Rocky Mountains except for minute quantities in the Sangre de Cristo and Sandia Mountains of Colorado and New Mexico. Maps will show their abundance and geographic variation with reference to six stratigraphic subdivisions designated as the Springer, Morrow, Lampasas, Des Moines, Missouri, and Virgil. Coal occurs in greatest thickness, 24 feet, in the Springer in the Pocahontas field, Virginia-West Virginia; 67 feet in the Morrow in the Cahaba field, Alabama; 91 feet in the Lampasas in western Virginia; 112 feet in the Des Moines in the southern anthracite field, Pennsylvania; 72 feet in the Missouri in the southern anthracite field, Pennsylvania; and 28 feet in the Virgil in southeswtern Pennsylvania. Variations are shown (1) in total coal thickness, (2) in frequency of coal beds, (3) in percentage of coal in the total column; and in relation between coal total thickness and the following ratios: (4) clastic-nonclastic, (5) sand-shale, and (6) marine-nonmarine sediment ratio.

Coal and marine sediments have inverse relations. Coal is largely restricted to areas with high clastic-nonclastic ratio. Relations between coal variation and total sediment thickness are inconsistent, as shown by great coal thickness in the geosynclinal section of western Virginia and also in the moderately thin craton section of central western Indiana.

Analysis of data for this paper was made with the co-operation of Miss Margaret Parker, who set up the data on I.B.M. cards.

UPLAND MEADOWS OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA

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Upland meadows clustered about the Great Western Divide, in the southern Sierra Nevada of California, are found on the Boreal Plateau erosion surface, south of what has been defined as the southern limit of Wisconsin (Tioga) glaciation. Meadows occupy closed basins, drained by streams which cut through rock-bound gorges. Sequential stages of meadow development found in 12 meadows are (1) lakes and swamps, (2) grasslands, (3) trenched grasslands, and (4) dissected basins of stream excavation. In the trenched grasslands finely bedded organic sediments, silts, and sands, deposited in shallow fresh-water lakes, are exposed.

Origin of lake basins on uplifted erosion surfaces is considered, and the conclusion is offered that these basins are glacial features, produced in a pre-Wisconsin glacial stage of the Cordilleran glacial complex.

MINERALOGIC STUDIES ON THE COLORADO PLATEAU

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The primary studies on the mineralogy of the Colorado Plateau, such as the establishment of standards for x-ray identification of uranium and associated minerals, techniques for separating and

studying radioactive minerals, and acquaintance with Colorado Pleatau minerals and mineral assemblages, have reached the stage where the mineralogic study of the Plateau uranium ores is progressing rapidly. About 20 uranium minerals and several uranium-bearing minerals or organic materials have been identified, as well as many associated minerals. The principal uranium minerals are uraninite and pitchblende, hydrous oxides, carbonates, sulfates, phosphates, arsenates, vanadates, and silicates. The chief metals associated with the uranium are vanadium and/or copper. The minor metals are lead, zinc, cobalt, nickel, manganese, silver, molybdenum, gold, arsenic, and selenium. Hummerite and montroseite, two new vanadium minerals, have been described. A possible new uranium mineral and several other possible new vanadium minerals are being investigated.

Recent work suggests that carnotite ore is restricted to near-surface deposits in the zone of oxidation. Black uranium-vanadium ore occurs in scattered surface deposits and in the few deep deposits so far known in western Colorado. It is less oxidized and contains more sulfides than the carnotite ore. Present study of several new minerals from the black ore is concerned with the paragenesis of the uranium-vanadium ores. The minerals of areas containing copper, of which the White Canyon district, San Juan County, Utah, has been most thoroughly studied, are uraninite, copper, and iron sulfides (with minor amounts of galena), sphalerite, cobalt and nickel minerals, and many secondary hydrous oxides, carbonates, and sulfates of uranium and other metals. Altered wall rock in the White Canyon district contains jarosite, alunite, kaolinite, allophane, and gibbsite.

FLUID INCLUSIONS IN MINERALS FROM THE ZONED PEGMATITES OF THE BLACK HILLS, SOUTH DAKOTA, AND THEIR SIGNIFICANCE

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A study of fluid inclusions in minerals from zoned pegmatites was undertaken as a check on the theory of zonal development through fractional crystallization in a restricted system. Beryl, spodumene, and garnet gave results that showed general agreement; the most extensive results were obtained from beryl.

Temperature determinations were made by heating polished-mineral sections under the microscope and recording the temperature of disappearance of the vapor phases of the fluid inclusions.

Beryl from outer zones of the Highland Lode and Bob Ingersoll No. 1 pegmatites yielded higher temperatures than beryl from inner zones. Results from the Peerless and Bob Ingersoll No. 2 pegmatites were inconclusive or contradictory. No other pegmatites yielded enough data to allow establishment of any temperature trends.

Temperatures observed in beryl ranged from 216° to 515°C. Results from individual crystals showed a range of 9° to nearly 200°C., and individual zones gave ranges of 65° to 230°C.

Data were too meager to permit presentation of conclusions, but results give tentative support to the hypothesis of fractional crystallization. Estimates of pressures prevalent at the time of crystallization indicate that some of the early-forming beryl crystallized at temperatures in excess of 500°C.

PRACTICAL NOTATION AND ARRANGEMENT OF THE CRYSTAL CLASSES

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The notations and arrangements of the 32 crystal classes adopted in current reference works can be criticised as inadequate in practical respects. They are not easy to remember, nor convenient to write and print, nor yet suited for consideration of macroscopic physical properties. We show a notation for the classes, based on modified international symbols for 13 kinds of macroscopic symmetry axes, and put into a 4 by 12 tabular arrangement, which we have found to be more practical in several

respects. Some physical properties of interest in crystallography include for both isotropic and monocrystalline solids the following:

Voigt-Bhagavantam	Jahn	Constants	Examples
		Centric Phenomena	
vector-vector	$[V^2]$	1–6	Dielectric susceptibility, crystal optics, etc.
scalar-tensor	$[V^2]$	1–6	Thermal expansion.
tensor-tensor	$[[V^2]^2]$	2–21	Elasticity.
tensor-tensor	$[V^2]^2$	2–36	Photoelasticity.
		Acentric Phenomena	
scalar-vector	V	1–3	Hydrostatic piezoelectricity, etc.
pseudoscalar-tensor	$\epsilon[V^2]$	1–6	Optical rotation.
vector-tensor	$V[V^2]$	1–18	Piezoelectricity, electro-optics.

PERMO(?)-TRIASSIC GEOSYNCLINAL FACIES IN NORTHEASTERN NEVADA AND NORTHWESTERN UTAH*

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In southeastern Elko County, northeastern Nevada, Wheeler, Scott, and Thompson (1949) note the presence of a post-Oquirrh, Permian (Guadalupian) sequence consisting of a Park City-Phosphoria-like unit (Gerster formation). These strata are unconformably overlain by an early Triassic to basal Jurassic(?) succession, which closely fits the descriptions of the Dinwoody, Thaynes, Timothy, Shinarump, Chinle, and Nugget formations. This Permo-Triassic section, most of which is typical of the Rocky Mountain-Colorado Plateau cratonic facies, is indicated by Wheeler and McNair (1950) to occur in a westerly overthrust plate.

At several other localities in northeastern Nevada and adjacent northwestern Utah, a sequence of miogeosynclinal shales, measuring several thousand feet, and ranging from late Permian(?) to post-*Meekoceras* Triassic, occurs in structures truncated by the overriding thrust. These shales are in part similar in lithology and fossil content to the Dinwoody formation of southeastern Idaho, western Wyoming, and southwestern Montana, and they lie along the logical invasion route extending from southern California northeastward to the northern Rocky Mountain region. Thus they are interpreted to represent a regional segment of the long-missing, latest Permian(?) and Triassic miogeosynclinal marine record deposited between the above-mentioned shelf and eastern miogeosynclinal facies on the east, and the eugeosynclinal facies to the west. Moreover, by eliminating the post-Triassic crustal shortening involved, the eastward Triassic transgression from the invasion trough in Nevada onto the bordering craton in Utah is demonstrated.

THREE-DIMENSIONAL PICTURE OF STEAMBOAT SPRINGS, NEVADA

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Diamond drilling by the Geological Survey has added immeasurably to an understanding of the structure, mineral deposition, rock alteration, temperature relations, and migration of water at Steamboat Springs.

The thermal history is long and involved, perhaps extending throughout Quaternary time. The

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dominant structure appears to be a west-dipping thrust fault, with springs emerging from east-dipping normal faults in the hanging wall of the thrust.

Six drill holes 400 to 686 feet deep indicate a maximum or near-maximum temperature for each hole at depths of 200 to 360 feet below water level; maximum temperatures are 318° to 342°F. At greater depths temperatures level off, or decrease slightly below main structures serving as channelways. The most satisfactory interpretation of these relations is: At considerably greater depths, a volcanic component (probably steam with dissolved substances) and meteoric water mix with proportions and temperatures such that a single liquid phase results, with a temperature probably little above 342°F. This water rises with minor loss of temperature by conduction, except on margins of the thermal area, until it is within several hundred feet of the surface. With further rise and decrease of pressure, a vapor phase forms. The high near-surface geothermal gradient is largely due to boiling. Dissolved gases tend to lower the boiling range below that of pure water, whereas dissolved solids have an opposite effect.

Near the surface some meteoric water mixes with thermal water on margins of the area. Hydrodynamic head and density, which is a function of temperature, are controlling factors.

DISCONTINUITIES IN TILL SHEETS

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Data on the glacial geology of 10 counties in the Allegheny plateau of northeastern Ohio were collected in part as a result of ground-water investigations made co-operatively by the U. S. Geological Survey and the Ohio Division of Water. A considerable part of the 10-county area was glaciated by the Illinoian ice and by three Wisconsin advances—Tazewell, early Cary, and late Cary. Within this area of four ice advances are many exposures where only one or two till sheets are present. None of the till sheets, therefore, forms a continuous blanket.

The distinctive clayey till of the last advance—the late Cary—is absent through lack of deposition from many tracts of a few acres to 10 or more square miles, as evidenced by extensive strip-mine and other exposures in uneroded, flat surfaces within the area covered by this ice. In some counties almost half the area within the late Cary margin lacks the clayey till. Where it is present this till at many places is only 4–10 feet thick. Similarly, in the area of early Cary glaciation which the later ice did not reach, the uppermost till is not everywhere early Cary, but may be Tazewell or Illinoian.

Although buried till sheets may be discontinuous because of both erosion and nondeposition the uppermost till sheet is discontinuous almost entirely because of nondeposition.

STRUCTURAL CONTROL IN THE VERMONT COPPER DISTRICT

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The copper deposits of Orange County, Vermont, are lenticular bodies of more or less massive pyrrhotite with minor amounts of chalcopyrite. Their wall rocks are mica schists, calcareous schists, and amphibolites of probable Ordovician age. The ore deposits were probably formed in Late Devonian time.

The broad arch in the schistosity dominates the regional structure. The copper district is a north-trending belt on the eastern flank of this arch. Both the schistosity and the arch were formed by differential upward flowage of the rocks in the crestal area. Undeformed porphyroblasts of kyanite, staurolite, and locally sillimanite in the rocks of the copper district show that the thermal peak of metamorphism followed most of this deformation.

Further slight deformation of the already schistose rocks provided the openings or potential voids for the introduction of the sulfides. This final movement consisted in a rise of rocks on the east rela-

tive to rocks on the west. At the Ely mine, the sulfide veins and lenses lie parallel to schistosity on the short limb of a broad open roll in the schistosity; the ore shoot follows the axis of the roll. In the Elizabeth deposit, which lies along a fault plane, the most spectacular ore shoots occur where the schistosity is conspicuously deranged by drag on the fault. Some of the gangue minerals, notably andesine, garnet, and hornblende, indicate that the rock temperature was still high at the time the ore was deposited.

MIDDLE ORDOVICIAN GRAPTOLITES FROM OKLAHOMA

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Blocks from the lower Viola limestone have been dissolved in hydrochloric and hydrofluoric acid, and graptolites picked out from the residue. Young stages of growth may be rendered translucent by treatment with concentrated nitric acid and potassium chlorate. Species of *Dicellograptus*, *Orthograptus*, *Climacograptus*, and *Cryptograptus* have been recognized, and other genera are present. A fairly complete growth series of *Climacograptus* sp. has been obtained, and less complete series of the other genera named. Almost nothing was known previously of the development of *Dicellograptus*. Developmental stages of *Cryptograptus* earlier than any so far described are now available.

SUTTER BUTTES RESTUDIED

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Since the work of Williams on the Marysville Buttes (1929—now officially called Sutter Buttes) evidence has been found modifying some of the ideas then expressed concerning their evolution.

It is no longer believed that they are a denuded laccolith, result of a single andesite intrusion, but rather a complex of andesite intrusions of at least three ages which form a stocklike core 4 miles in diameter. Rhyolite plugs surrounding this core are not the last intrusive phase, though they are later than some of the andesite intrusions. Rhyolite tuff, however, found at the base of associated volcanic sediments surrounding the central core, marked the initial explosive phase and was erupted before appreciable deformation of pre-volcanic sedimentary rocks. The buttes themselves are andesite plugs later than the rhyolite plugs and probably later than the central vent tuff, formerly thought to have been the final phase of activity. They protruded through earlier intrusions and sedimentary cover to form great spines from which originated the youngest, very coarse lahars. Andesite block-lava flows, originating at vents in the peripheral sedimentary ring, closed the volcanic epoch.

The slow accretion of the central core caused progressive deformation of pre-volcanic and volcanic sedimentary beds, resulting in an unconformity which transgresses all but the final deposits of volcanic debris.

CONTRACTION THEORY OF MOUNTAIN BUILDING

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Jeffreys has stated the general basis for the contraction theory by which Scheidegger has explained the circular shape of many island arcs with reasons for the location and direction of motion of associated earthquakes. By it Coulomb and Gunn have offered an explanation supported by Ewing's observations for the gravity anomalies and ocean deeps accompanying arcs.

It was suggested by Gill that the earth started with a uniform basic surface without continents. The first arcs to form were small. Multiple aggregations of them formed continental nuclei now

preserved on several continents as Keewatin type rocks. Marginal shelves formed by erosion served as centers for new arcuate fractures above which acid lavas, steam, and gases rose superheated (from great depths as associated deep earthquakes show) to form continents, oceans, and air. The present rates of volcanism and erosion are adequate to have produced this growth.

As the seas behind arcs became filled and island arcs changed to primary mountains the continents grew, and fresh arcs formed farther outward. Arcs can be seen to have become larger as the earth cooled. Arcs tend to join into great belts of fracture by which the earth contracts. Shallow, horizontal adjustments accompanied by basalts have given rise to graben and to rifts especially on either side of the Indian and Pacific oceans.

It is held that this theory is physically sound and that such detailed studies as have been made show that it explains geological observations fairly precisely.

DISTINCTION BETWEEN PRIMARY AND SECONDARY MOUNTAINS

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The two active orogenetic belts of the earth along which its present contraction is concentrated are approximately great circles intersecting in a T at Celebes. Each consists of a series of usually circular mountain or island arcs (and some irregular or in the southwest Pacific straight elements). These arcs are convex toward adjacent oceans, join in cusps, and are accompanied by (1) all the deep and most of the shallow earthquakes, (2) extensive metamorphism and all recent batholiths and active acid volcanoes, (3) strips of negative gravity anomalies, (4) ocean trenches, (5) no underlying basement.

In North America and South America and Europe inland from these active primary mountains are other secondary arcs of folded sediments commonly centered about the cusps of primary mountains, concave toward adjacent oceans and largely lacking the foregoing features.

In the Appalachians secondary arcs occur according to King at northern Newfoundland, Gaspe, Lake Champlain, Pennsylvania, Tennessee, Ouachita Mountains, and Marathon Mountains while parts of metamorphic primary arcs linking them crop out only in Maritime, New England, and Piedmont regions.

In the Precambrian, Proterozoic, and Timiskaming rocks are roots of former secondary mountains, and Archean rocks (including Keewatin, but excluding Timiskaming) are primary. For example, Grenville or Laurentian primary arcs may link secondary arcs at Minnesota, Sudbury, Mistassini, and Lake Michikaman. The Timiskaming type of rocks on each continent represent secondary deposits formed on the multiple Keewatin primary arcs in the manner described by Hewitt.

Each continent consists solely of primary belts partly covered and hidden by secondary mountains and deposits. The older primary arcs are successively smaller back to the Keewatin.

SUBDIVISION OF THE CANADIAN SHIELD

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In the exposed shield six provinces are separated by great faults along Snare River, Great Slave Lake, Nelson River, Huron-Mistassini fault zone extended across Labrador, and east of the Labrador trough. Doubtless other hidden provinces exist.

The Grenville or Laurentian province has a structure similar to the Sierra Nevada. From that, and by analogy with the Appalachians in which folding, igneous activity, and pegmatites are contemporaneous, dated pegmatites show the Laurentian province to have been mountain built from 8 to 11×10^8 years ago, the Athabasca province from 16 to 19×10^8 years ago, the Great Bear Lake province more than 14×10^8 years ago, and from structure the Labrador coast more than 11×10^8 years ago.

Besides these four gneissic provinces, two of greenstone type have been recognized composed of volcanics, graywackes, granites, and gneisses. These at more than two billion years old are the nuclei and represent a separate division of Precambrian time like similar provinces in Australia and Africa.

Former secondary mountains are represented by Timiskaming rocks and by arcs of Proterozoic rocks of widely diverse age whose thickest, most folded remnants are infaulted against Keewatin or province boundary faults. Each remnant rests upon an older primary province but is faulted against an associated younger one.

Other great faults of economic significance strike inward from each successive marginal province in directions approximately predicted by physical theory of shear failure.

STRATIGRAPHIC IMPLICATIONS OF CAMBRO-ORDOVICIAN ATLANTIC PROVINCE TRILOBITES, MARATHON UPLIFT, TEXAS*

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Trilobite faunas in the Marathon folded belt of West Texas (1) from the Lower Ordovician beds of the Dagger Flat and Marathon formations, and (2) from Upper Cambrian and Lower Ordovician exotic limestone boulders near the top of the Mid-Ordovician Woods Hollow shale are of particular interest because many genera belong to the Atlantic province rather than to the near-by North American faunal realm. Probably the Late Cambrian and Tremadocian olenid faunas of South America were distributed northward through the Andean and Ouachita troughs and east and southeastward around an outer Appalachian trough to Acadia and Europe.

The exotic boulders show in part a mixture of trilobite genera of both Atlantic and North American provinces in a less terrigenous lithofacies than that of the shale and flaggy limestone of the Cambro-Ordovician sequence found in place. They are probably erosional remnants from an Ordovician uplift toward the foreland side of the trough and present problems similar to those of the Rysedorf and Levis conglomerates.

The mixed faunas in the boulders enable more-detailed correlation between the two provinces. The American *Cedaria* zone is probably older than any olenid fauna in this area. *Parabolinella evansi* and *Eurycare* sp. are associated with a high *Aphelaspis* fauna. Tremadocian genera from the boulders indicate contemporaneity with the Dagger Flat and lowest Marathon limestone based on associations in Europe and South America; genera in the same rocks show equivalence to the American Gasconade and possibly Roubidoux (Tanyard and Gormon of the Ellenburger group).

PALEOCENE MAMMALIAN GENUS *ELLIPSODON*

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The exceedingly rare mammalian species, *Ellipsodon inaequidens*, is the type of the Paleocene genus *Ellipsodon* Scott, 1892. The type specimen is poorly preserved, and the few certainly referable specimens fragmentary. Several species other than the type have been assigned to the genus, the better characterized of which are: *E. lemuroides*, *E. acolytus*, and *E. aquilonius*. These were known to be unlike *E. inaequidens* in several structures, and a strong possibility has always existed that the true relationships of the genus as based on them were misunderstood. Recently obtained material of a species closely related to *E. inaequidens* demonstrates that, although *Ellipsodon* is a mioclaenine condylarth as previously thought, most of the species formerly assigned to it must be removed. For these, the name *Promioclaenus* Trouessart, 1904 seems available. To *Ellipsodon*, in addition to the type, is to be assigned an unnamed species from the Nacimiento formation of northern New Mexico, and possibly *E.? sternbergi* from the North Horn formation of central Utah.

The new specimens of *Ellipsodon* show that in this genus: (1) the lower jaw is short and stout;

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(2) the dental formula is ?/2?, 1/1, 3?/3, 3/3; (3) the lower premolars are moderately inflated, short and wide, crowded (set obliquely in jaw), and have small but distinct heels which are expanded transversely and basined internally.

CARY AND MANKATO GLACIATION IN CENTRAL AND NORTHEASTERN MINNESOTA*

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Minnesota has a doubly unique position in the glaciated area of North America in having been twice invaded by ice lobes from three centers of flow during Cary and again during Mankato substages of the Wisconsin glacial age—by the Des Moines lobe from the northwest ("Keewatin center"), Rainy lobe from the north ("Patrician"), and Superior lobe from the northeast ("Labradorian").

In Cary time the Rainy lobe was first to advance, but its brown drift was soon overrun by the Superior lobe. The Superior lobe advanced to central Minnesota, where its red drift generally overlies but is locally interbedded and interthrust with buff drift of the Des Moines lobe.

During the Two Creeks interval the Superior lobe retreated far enough into Lake Superior basin to permit accumulation of red lake clays. In Mankato time the Superior lobe was first to readvance, and it incorporated the red lake clays to make red clayey till (*cf* Valders till of Northeastern Wisconsin). The Des Moines lobe then readvanced and locally buried the red clayey till. The position of the Rainy lobe in Mankato time has not been delineated.

The above sequence differs from that of Leverett principally in (1) the positive identification of a Cary advance from the Des Moines lobe, first inferred for southern Minnesota by Ruhe; (2) Superior lobe source rather than "Patrician" source for the Cary red sandy drift of central and eastern Minnesota; and (3) recognition that Mankato Superior till is consistently clayey in contrast to its sandy Cary predecessor, and forms a patchy veneer over a much broader area than previously mapped.

PSEUDOSYMMETRY AND ATOMIC PATTERNS OF CRYSTALS

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One set of instances in which it can be demonstrated that the pseudosymmetry of a crystal of known composition provides a pointer to the general nature of the atomic pattern is exemplified by orthorhombic staurolite $H_2FeAl_4Si_2O_{13}$, for which $a:b:c = 0.4734:1:0.3414 \sim \sqrt{2}:3:1 = 2:3\sqrt{2}:\sqrt{2}$. Here the companion cell (with vertices actually on a cubic lattice) has displacements z[002], s[330], s'[$\bar{1}$10], and volume 12, all in the scale of some metric k in the range a/2, b/3$\sqrt{2}$, c/$\sqrt{2}$. Another set is exemplified by orthorhombic chrysoberyl $BeAl_2O_4$ for which $a:b:c = 0.470:1:0.580 \sim \sqrt{2}:3:\sqrt{3} = \frac{3}{2}\sqrt{3}:\sqrt{6}:\sqrt{2}$, with the corresponding displacements $\frac{3}{2}$ t[111], r[11$\bar{2}$], s[$\bar{1}$10], and volume 4, in the scale of a metric k in the range $\frac{1}{2}$ a$\sqrt{3}$, b/$\sqrt{6}$, c/$\sqrt{2}$. Two interesting conclusions follow. (1) For staurolite, $12k^3$ provides $48 = 12 \times 4$ close-packed sites, suggesting that Z = 4: for chrysoberyl, $4k^3$ provides $16 = 4 \times 4$ such sites, suggesting that here too Z = 4. (2) That the close-packed sites for staurolite are cubic (*i.e.*, fcc) is shown by the z, s, s' displacements of the companion cell, since the required symmetry elements for this orthorhomibc crystal associated with each of these directions (2, m, or 2/m) lie within the cubic system. On the other hand, such symmetry elements associated with r and t displacements do not lie within the cubic system. We infer from the r, s, t nature of the displacements for chrysoberyl that the close-packed sites in this crystal are of double cubic, not of cubic, type.

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ECOLOGICAL INTERPRETATIONS OF AN UPPER CRETACEOUS DEPOSITION NEAR SAGE JUNCTION, WYOMING*

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The section dealt with herein is exposed in SE 1/4 Sec. 7, T. 21 N., R. 119 W., Lincoln County, Wyoming. It is about two-thirds of a mile east of Sage Junction and on the north side of Highway 30N. It consists of about 1100 feet of shales, siltstones, porcellainites, sandstones, coal seams, and coquinas.

The sequence generally dips about 35° NW. On the basis of the available collections of fossil mollusks, it is assigned to the lower part of the Leeds Creek strata (Upper Cretaceous). The entire section may be traced into 18 units: the top part of the sequence (Units 18-11) represents fresh-water facies; the middle part (Units 9-6) represents a true marine shallow-water facies of short duration; the lower part (Units 5-2) indicates a brackish-water sedimentation; and the bottom unit yields molluscan species of fresh-water origin, representing fluviatile facies.

Further interpretations may be supported by the rich fossil content of some of the units: the presence of *Melampoides* or related genera in Unit 11 may well indicate muddy and shallow water close to the shore of an estuarine area, which was probably not distant from the sea; the coquina of Unit 6 probably represents a drifted assemblage on a seashore; the occurrence of *Brachydontes*-like genera in Unit 9 may imply presence of rocky bottom or hard objects off shore near by in sheltered water of low salinity. Since these sessile forms usually occupied the greater part of the rock surface and made the habitat unfavorable for other forms, they soon became dominant in the community. This fact explains why a large numbes of *Brachydontes* or related genera were found in the deposit, but little of anything else in the assemblage. If other species were found in large number, *Brachydlotes* was often represented by imperfect or fragmentary specimens.

UPPER CRETACEOUS NONMARINE MOLLUSCAN FAUNA FROM COKEVILLE, WYOMING*

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Smithsonian Institution, Washington, D. C.

A series of shales and limestones is exposed in the vicinity of Cokeville, Wyoming, which yields a rich molluscan fauna of nonmarine habitat. These strata overlie the variegated shales at Thomas Fork, which are in turn underlain by deposits of black shale well exposed on Smiths Fork. The strata are overlain by the variegated shales of Dry Fork, which underlie a series of silty limestones, dark argillaceous and calcareous shales, and porcellanites, all of fresh-water origin, which include at various intervals coquinas of brackish-water origin and light-colored and tan sandstones of marine origin. No fossils have so far been found in the variegated shales, but the beds above and below the strata at Cokeville are in general richly fossiliferous.

The molluscan fauna of the Cokeville beds consists of species of the bivalves: *Ostrea*, *Brachydontes*, *Corbula*, *Corbicula*, and *Unio*; of the gastropods: *Mesoneritina*, "*Helicina*", *Viviparus*, *Campeloma*, *Lioplacodes*, *Valvata*, *Mesocochliopa*, *Parateinostoma*, *Parhydrobia*, *Pyrgulifera*, *Pachychiloides*, *Zaptychius*, *Melampoides*, *Rhytophorus*, *Physa*, *Lymnaea*, *Gyraulus*, and *Anisopsis*. The lower part of the sequence contains a few species in common with the Bear River strata, together with a number of new species congeneric with those of that formation. The upper part yields fewer species in common with the Bear River, but more forms resembling closely those of the overlying deposits.

The succession and differentiation of the faunas are well demonstrated in this sequence. A certain

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percentage of the molluscan forms is common to adjacent beds, but new elements appear at different levels and represent successive age units.

DIOPSIDE—WATER SYSTEM

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The diopside—water system has been investigated up to 6500 bars by means of sealed platinum tubes held in an internally heated, high-pressure vessel. The melting point of diopside is lowered from 1391°C. at atmospheric pressure to 1289°C. at the maximum pressure of water vapor applied. This lowering is considerably less than the measured lowering (~400°) of the melting point of albite under the same vapor pressure of water.

It was not feasible to quench the melt to a glass under the conditions of most of the experiments; hence a quantitative measure of the water content of the liquid could not be obtained. However, the preliminary experiments support the view that a basaltic magma contains much less water than a granitic magma.

ICE-PUSH STUDIES ON WAMPLERS LAKE, MICHIGAN*

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Field observations during the winter of 1951–1952 on Wamplers Lake in southeastern Michigan resulted in measurements on the movement of the sheet of lake ice in response to air-temperature fluctuations.

The following generalities are made as a result of the study:

(1) A temperature rise of 1°F. per hour prolonged over a period of 12 hours on an 8-inch ice sheet is sufficient to cause thrust on a shore composed of unconsolidated glacial outwash containing some boulders.

(2) The direction of ice thrust against the shore is not everywhere orthogonal to the trend of the shore line on an elongate lake, but may be oblique at certain points.

(3) Tensional fracturing of the ice due to rapid cooling results in one set of cracks that radiate from the central part of the lake, and another set roughly concentric with the shore line.

Wamplers Lake is about 2 miles long and 1 mile wide.

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* This work was done under the auspices of the Snow Ice and Permafrost Research Establishment, Corps of Engineers, U. S. Army, under contract DA-11-190-ENG-2.

ABSTRACTS OF PAPERS SUBMITTED TO THE MEETING IN TUCSON, APRIL 11–12, 1952

CORDILLERAN SECTION OF GSA AND WEST COAST SECTION OF PS

NEW EVIDENCE ESTABLISHES PERMIAN AGE FOR THE DEKKAS ANDESITE, SHASTA COUNTY, CALIFORNIA

J. P. Albers and J. F. Robertson
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The Dekkas andesite of northern California, a formation composed essentially of andesitic tuffs, andesite flows, and mudstone lenses, was considered Triassic by J. S. Diller in 1906. In 1939 H. E. Wheeler assigned it, chiefly on the basis of regional correlations, to the late Anthracolithic (Permian). Geologic mapping during 1950 and 1951 in the Shasta Lake area revealed new evidence that conclusively establishes its age as late Permian. This evidence consists of:

(1) Well-preserved Permian fossils contained in two sedimentary beds in the Dekkas andesite. The genera, identified by C. W. Merriam and L. C. Henbest, include *Dictyoclostus*, *Camarophoria* and *Parafusulina*.

(2) A structural divergence that suggests an unconformable relationship between the Dekkas andesite and overlying Middle Triassic rocks.

The Dekkas andesite is at least 3500 feet thick—considerably greater than was formerly supposed; in addition, the overlying Bully Hill rhyolite of Diller is now recognized as a series of surficial lava flows and pyroclastic rocks. The lithologic section in the Shasta Lake area, revised to incorporate these data, is even more closely similar to the representative Permian section of the northern Sierra Nevada (Blairsden locality) and the Koipato formation of the Humboldt Range, Nevada, than was ndicated by Wheeler.

CARRIZOZO MALPAIS, NEW MEXICO

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The Carrizozo olivine basalt flow, near the north end of the Tularosa Basin, New Mexico, is among the more recent of similar post-Pleistocene flows in the western States. It is far less weathered than the 1200-year old McCartys flow in northwestern New Mexico described by Nichols (1946). The Carrizozo flow exhibits features of recent lava flows of similar composition such as flow units, pressure ridges, collapsed lava tubes, and kipukas. Numerous squeeze-ups, and grooved, ropy, vesicular, and banded lava may be seen at the surface.

The flow is 44 miles long, has a total area of about 127 square miles, and a volume of lava of approximately 1 cubic mile. It spreads out to a width of 3–4 miles from the base of a low cinder cone 11 miles north of Carrizozo, thence extends southwest down the west side of the valley. West of Carrizozo it narrows abruptly, and for 10 miles is about 1 mile wide. Farther south in the Tularosa Basin west of Three Rivers the final 20 miles of the flow is nearly 5 miles wide, and consists of at least 7 flow units.

The average gradient is 30 feet per mile. Average thicknesses, determined from surrounding topography, range from 25 feet west of Three Rivers to 70 feet near the source. Maximum thickness west of Carrizozo of over 120 feet is suggested by a deep pit in the lava on the valley axis.

GEOLOGY OF CAPITAN QUADRANGLE, NEW MEXICO

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The Capitan quadrangle, east-central New Mexico, lies across the boundary of the Basin Range and Great Plains provinces. It is underlain by the east limb of a N. 10–20° E. trending synclinorium with outcropping Permian, Triassic, and Cretaceous sediments and lower Tertiary volcanics, in-

truded by a middle Tertiary basic dike swarm and larger siliceous bodies. Drainage superpositions within the area are proven by numerous water gaps and remnants of post-Laramide gravels on east-sloping ridges.

Upper Permian San Andres limestone (685′) underlies Triassic (?) Bernal red quartz sandstone and shale (354′), Santa Rosa quartz sandstone and chert conglomerate (295′), and Chinle red siltstone and mudstone (181′). Upper Cretaceous Dakota sandstone (134′) unconformably overlies Triassic and underlies Mancos shale and limestone (389′) and Mesa Verde sandstone, shale, and coal (534+′). Tertiary volcanics of unknown thickness partly cover older rocks.

Hundreds of basic dikes up to 50 feet thick, trending about N. 20° E., indicate crustal extension of over 1 mile in the Mesa Verde terrain. Regional north-south structures are transected by local east-trending faults and folds related to the elongated Capitan microgranite laccolith which extends eastward beyond the quadrangle into the Pecos Basin.

Three rhyolite- and trachyte porphyry domes (?) 3–4 miles in diameter and one diorite stock 1 mile in diameter form prominent peaks along the west edge of the map area, aligned parallel to the regional structures.

Gold has been mined adjacent to the two southernmost intrusions, and magnetite deposits occur in San Andres limestone tactite above the Capitan Mountain intrusive.

GEOCHRONOLOGY OF THE DEGLACIAL AND NEOTHERMAL AGES

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This is a review of the chronologies based on varved (annually laminated) sediments and a revision of the estimates of the gaps in the varved data. A Finno-Swedish chronology by Gerard De Geer, Ragnar Lidén, and Matti Sauramo covers the last 11,500 years. It is based on 10,500 varves and on 650 historical and 380 interpolated years.

The North American chronology ends during the Cochrane ice readvances south of James Bay. These are correlated with the comparably located Nyland and Salpausselkä halts of Younger Dryas age in southern Finland. The Cochrane halt is thereby dated at about the millennium 11,000–10,000 years ago. Then, going backward in time, the Timiskaming retreat occupied 2025 counted years (varves) plus 525 estimated years (rapid retreat matches the sub-arctic Alleröd age), the Sioux Lookout-Pembroke halt 475 estimated years, and the Valders age 3200+ counted and 1800 estimated years. Thus the Valders-Mankato glacial maximum occurred 16,120 counted and 3180 estimated, or some 19,300, years ago. The estimates are low, not high. The radiocarbon date 11,400 for the Two Creeks Forest Bed (about 11,000 for the Valders maximum) is unreasonable.

The Valders maximum (Manistee moraine) correlates in New England with the St. Johnsbury halt and probably (E. H. Perkins) with the Augusta-Belgrade outwash deposits, and the Two Creeks age with the rapid Hanover retreat. The ice retreat from Hackensack, N. J., to St. Johnsbury occupied 6700 counted plus 900 estimated years. The ice border left Hackensack at least 27,000 years ago.

FORAMINIFERAL EVIDENCE AS TO THE AGE OF THE PACIFIC COAST *CORALLIOCHAMA* BEDS

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In 1885 White described a Middle Cretaceous rudistid *Coralliochama* from beds near Gualala, California, and from Todos Santos Bay, Baja California. Subsequently this peculiar form was correlated with the Turonian (Anderson and Hanna, 1935) and with the Maestrichtian (Durham and Kirk, 1950). This last correlation was based upon the association of the ammonites *Nostoceras* and *Parapachydiscus catarinae* Anderson and Hanna with the *Coralliochama* beds.

Recent work on the Upper Cretaceous Foraminifera of California has revealed an occurrence of *Coralliochama* in the Carlsbad area of California. The Foraminifera of these beds have been correlated with the Upper Taylor faunas of the Gulf Coast and with the Upper Senonian (Middle Campanian) faunas of Europe. A *Coralliochama* occurrence at Point Loma, San Diego County, is also associated

with abundant and diagnostic Foraminifera, which here correlate with the Taylor beds of the Gulf Coast and with the Lower Campanian of Europe.

The contradictory evidence as to the age of the *Coralliochama* beds cannot be explained by redeposition of the rudistid fauna inasmuch as it would then signify that such fauna was originally from the Lower Senonian or older strata, thereby conflicting even more with the ammonite evidence. The Foraminifera in each case range throughout the shale beds and are well preserved with no indication of redeposition. Hence, it would seem that the most logical solution is that the range of *Parapachydiscus catarinae*, the nostocerid ammonites, and the *Coralliochama* fauna is of Campanian age.

EVIDENCE FROM SEISMOLOGY ON THE NATURE OF OROGENY

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Seismic evidence indicates that the principal orogenic structure responsible for each great linear and curvilinear mountain range and trench is a fault. Study of eight regions in which orogenic activity is in progress reveals that these great faults occur in two basic types, here designated oceanic and marginal. Oceanic faults, situated wholly within the oceanic domain, extend from the surface to depths of 350 to 700 km—the majority in the 600 to 700 km depth range. They exhibit an average dip of 53°. Their elastic strain-rebound characteristics show that these faults are composed of two separate mechanical units—a shallow component extending from the ocean bottom to the Mohorovicic discontinuity, which in the vicinity of the fault may be depressed to approximately 60 km, and a deeper component extending from the Mohorovicic discontinuity to the 700 km crustal boundary. The marginal faults occur in dual and triple forms. The dual faults comprise a shallow member extending from the surface to the depressed Mohorovicic discontinuity and an intermediate member extending to a depth of 200 to 300 km. The average angle of dip is 30°. The marginal triple form is similar to the dual down to the 300 km level. At this depth the angle of dip changes abruptly to 56° to form a third component extending to the 650± km boundary. The elastic strain-rebound characteristics of the marginal faults indicate that the components of these structures also move as separate units, although the two lower elements exhibit evidence for mechanical coupling. In the continental domain the 300 km level thus represents a tectonic discontinuity not revealed by seismic wave-propagation studies but which is apparently the lower boundary of the continents. In accordance with Hubbert's extension of the Mohr stress theory, the 30-degree dip of the upper two layers of marginal faults may be attributed to a stress pattern in which the greatest principal stress is a horizontal compression. The 56-degree dip of the oceanic faults and of the lower components of the marginal faults falls within the range of values calculated by Hubbert for normal faults. However, the direction of slip is reversed. Consequently it must be postulated that these are reverse faults generated by stress patterns in which the greatest principal stress is a vertical tension and the least principal stress is a horizontal compression.

METAMORPHOSED PERIDOTITE FROM THE SOUTHWESTERN MOJAVE DESERT, CALIFORNIA

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Although serpentinized peridotites commonly are intrusive into geosynclinal sediments of Upper Jurassic age in the Coast Range and Sierra Nevada geomorphic provinces of California, they are almost unknown in the Mojave Desert province. The mass here described is exposed on a half-square-mile area of an isolated butte in extreme western San Bernardino County, west of Adelanto. It is part of a sill-like body intrusive into pre-Cretaceous hornblende amphibolite schist, the remainder of which has been obliterated by invasion of Upper Jurassic (?) granite and by erosion. No geosynclinal sediments are associated with the amphibolite schist, which in places closely resembles a plutonic igneous rock.

Influx of granite has produced uniform mild metamorphism of serpentinized peridotite, away from the contact, with simple development of divergent groups of anthophyllite blades 1–4 inches long. Occasional patches of talc-tremolite rock of a few tens of feet in diameter have developed in possible response to concealed granite intrusions.

Close to the exposed granite contact pronounced interchange of material has resulted in development of complex mineral assemblages involving introduction of silicon, potassium, sodium, and boron. Disequilibrium assemblages such as muscovite, biotite, talc, chlorite, orthoclase, oligoclase, quartz, tourmaline, and relict serpentine are common in a contact zone which in places is 30 to 40 feet wide.

Following the main period of granitic intrusion hydrothermal activity has resulted in reversion of anthophyllite to serpentine and replacement of serpentine rock by carbonates, chiefly magnesite.

LARGE GAS BUBBLE PRESERVED ON A LAVA FLOW IN NORTHERN ARIZONA

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An unusual feature on the surface of a lava flow at the base of Merriam Crater in Coconino County, Arizona, is compared with a large gas bubble or blister on a flow from Parícutin Volcano in Mexico.

CHICO SERIES—GRAYWACKE, SUBGRAYWACKE, OR ARKOSE?

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The Chico series (Upper Cretaceous) of west-central California fills an important place in the Mesozoic history of the Coast Ranges and the Great Valley. The sediments were deposited in a geosyncline that covered over 40,000 square miles in central California alone, and these sediments average more than a mile in thickness.

Shale is the preponderant lithologic type, and it is associated with siltstone, sandstone, and coarse conglomerate. The sandstones typically contain angular grains of feldspar, quartz, biotite, rock fragments, and a consistent suite of heavy minerals. Feldspar is commonly the most abundant mineral. Uncemented sandstones are fairly well sorted and contain 5–25 per cent clay matrix; others are cemented with calcite.

A western provenance for the sediments is substantiated by heavy minerals, inclusions in quartz, rock fragments, and sedimentary structures. The conglomerates show that volcanic rocks formed the major source rock in the western provenance.

The sandstones, by virtue of their mineralogy and matrix, can be classified as either arkoses or graywackes on the diagrams of Krynine and Pettijohn, or as subgraywackes according to Tallman's classification. Genetically, the sandstones are not arkoses, and petrographically they are not true graywackes. It is suggested that the genetic inference ascribed to arkose be omitted for purposes of classification, and that the distinction between graywacke, subgraywacke, and arkose be made on the basis of texture (percentage of matrix) following the classification of Tallman.

DIVERSE BUT SIMULTANEOUS OROGENY

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Very diverse types of mountain making have affected at different times various structural provinces. Considered here is simultaneous occurrence of different types of orogeny, often in neighboring areas; this is heterosynorogeny. Exact contemporaneity of earlier orogenies is difficult to establish, but movements in late Pliocene-Recent interval permit generalization. Examples of heterosynorogeny in United States are:

California Coast Ranges have been folded during Quaternary along northwest oblique axes and simultaneously sheared horizontally by San Andreas and similar faults. Contemporaneously, in Basin-Range structural province next east which includes Sierra, normal block faulting, tilting, differential elevation of fault prisms occurred, apparently with east-west extension. Colorado Plateaus, Southern Rockies experienced broad uplift, some warping. Appalachian Quaternary movement is presumably broad upbowing.

Oregon-Washington Coast Ranges and Cascades suffered Quaternary upbowing, probably some gentle further folding along northerly axes, while northernmost Coast Ranges. Cascades, the Great

Basin province in Washington, Oregon, Idaho underwent post-middle-Pliocene (Rattlesnake) additional northwest to east-west folding. Upbowing, some north-south faulting, affected Northern Rockies.

Greatest contrasts in Quaternary orogeny are between California Coast Ranges and middle Great Basin, between Cascades and their southern prolongation in Sierra Nevada, and between middle and northern parts Great Basin province. Diversity in Quaternary orogeny is scarcely explicable by differences in formational constitution or in older structures, as often earlier deformation in same area was different type. Heterosynorogeny evidence favors different forces synchronously acting rather independently in individual tectonic areas of different sizes rather than pervasive continental or global forces.

OROGENIC SIGNIFICANCE OF TWO VOLCANIC SUITES AT UMNAK ISLAND, ALASKA

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Umnak in the Aleutian volcanic arc contains two contrasting petrographic suites of possible orogenic significance. A low shield volcano of plateau basalt affinities on northeast Umnak has a central caldera, 6 miles in diameter, and other indications of grabenlike structures. About 12 per cent of iron and 15 per cent of alumina characterize the aphyric basalts. Hypersthene is absent. A basement complex of hydrothermally altered volcanic rocks is at or below present sea level. Southwest Umnak, 15 miles nearer the Pacific basin, is crowned by two strato-volcanic cones consisting of hypersthene-bearing andesites that contain about 8 per cent of iron and 18 per cent of alumina. Many flows contain abundant, corroded andesine or sodic labradorite phenocrysts encased in calcic labradorite equivalent in composition to the groundmass labradorite. These andesitic rocks were extruded on a high erosional surface up to 1500 feet in altitude carved across folded argillite and tuff beds, hydrothermally altered volcanic rocks, and a quartz diorite pluton chemically similar to the overlying hypersthene-bearing porphyritic andesites.

The basalt volcano was apparently fed through tensional faults that tapped basaltic magmas beneath a thin sialic crust. The southwest Umnak hypersthene-bearing andesite cones were possibly derived by periodic downbuckling and incomplete fusion of quartz diorite and argillaceous rocks at the base of a thicker part of an ancient geosyncline. The suggested genetic relationship between the two Umnak rock suites may be analogous to that between andesites of the High Cascades and basalts of the Columbia plateaus.

NEPHRITE AND ASSOCIATED ROCKS AT LEECH LAKE MOUNTAIN, MENDOCINO COUNTY, CALIFORNIA

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Nephrite was first found in Mendocino County in stream-worn boulders along the middle fork of the Eel River and one of its tributaries, Williams Creek. Early in 1951 nephrite was found *in situ* at Leech Lake Mountain, about 12 miles northeast of Covelo.

The nephrite ranges from light green to dark green and occurs as irregular bodies and veins of varying widths in serpentine sills and at the original intrusive contact between serpentine and graywacke. Associated minerals include idocrase, hydrogrossularite, pectolite, and a diopsidic pyroxene. Formation of nephrite is related to the later stages of igneous activity.

Graywacke adjacent to the serpentine was weakly metamorphosed to a dark-gray, dense, hard rock and contains conspicuous rounded grains of brown hornblende rimmed by glaucophane.

In addition to sills of serpentine, there are several sills of pyroxenite ranging from 12 to 50 feet thick and separated by apparently undisturbed beds of cream and red chert. Although much of the pyroxenite in the sills is quite fresh, the rock in one sill has undergone slight alteration and is composed essentially of titan-augite with minor amounts of glaucophane.

MID-TERTIARY ROCK UNIT FROM SOUTHERN ARIZONA

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Fossils of late Cenozoic and Cretaceous age have been identified from southeastern Arizona, but none representing the intermediate time have heretofore been recorded. As a result, determination of the sequence of post-Cretaceous events in this area has not been possible.

Recent discovery of a Middle Tertiary fossil rhinoceros in deformed sedimentary beds in the San Pedro valley near Redington shows major deformation there in post-Middle Tertiary time. Lithologically, the sediments containing the fossil indicate a source considerably lower than the surrounding mountains and a climate probably somewhat more humid than that of today.

LAKE ROGERS, A PLEISTOCENE LAKE IN THE NORTH END OF DEATH VALLEY, CALIFORNIA

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Dissected lake beds occur in the northern end of Death Valley at an elevation of approximately 2500 feet. They extend from about 2 miles north of Ubehebe Craters for 6 miles in a northwesterly direction, and attain a width of 3–4 miles. The beds are flat lying and rest in places on an eroded surface cut on a lava flow interbedded with tilted fanglomerate, and in other places directly upon alluvial fan material.

The lake beds are approximately 40 feet thick in the southern part and thin to the northwest. Cinders from Ubehebe Craters overlie the beds in some localities but are not incorporated in the sediments. Bone fragments weathering out of the lake beds led to the discovery of a 3-foot section of a tusk, probably Mastodon, that had already weathered out and been buried in Recent alluvium.

The beds are obviously younger than the fanglomerate with its intercalated lava and older than the Ubehebe eruptions. In the opinion of the writer, the former is early Pleistocene, the latter Recent. The suggestion, therefore, is that the lake in which the sediments were deposited was present in late Pleistocene time and probably was contemporaneous with the later stage of Lake Manly in the southern part of Death Valley (late Wisconsin).

It is proposed to apply the name Lake Rogers to this former lake in honor of John Rogers, who with William Lewis Manly safely led the Bennett-Arcane party out of Death Valley in 1849.

POST-CAMBRIAN FAULTING IN THE BLACK HILLS, YAVAPAI COUNTY, ARIZONA

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The oldest post-Cambrian faults of the Black Hills displace Paleozoic rocks, but not Tertiary. West of these faults, which are along the northwest front of the range, Tertiary rocks rest on Precambrian rocks; east of them, Tertiary rocks rest on Paleozoic rocks, indicating that the upthrown side is on the west (valley side). These oldest faults are largely obliterated by younger faults.

The later period of normal faulting displaced late Tertiary rocks and resulted in elevation of the Black Hills. Along the western margin of the Black Hills these later faults dip westward, and along the eastern margin of the range most of them dip eastward. But along the northeastern side of the range, some of the normal faults dip westward. Where possible, the stratigraphic throw or vertical separation was determined. Along the western side of the range, the stratigraphic throw decreases northward and southward to 200 feet from a centrally located maximum throw of about 1200 feet. Along the east-central side of the range, the maximum throw was 2850 feet. Southward from this point, the stratigraphic throw could not be determined. Northward it decreases progressively, and farther north the west-dipping normal faults (antithetic) so predominate that the sum of their stratigraphic throw is 200 feet greater than that of the east-dipping normal faults. Still farther north all the faults die out in a monocline, indicating that where deformation was less severe, the rocks yielded by flexure rather than rupture.

BRECCIATED GABBRO PEGMATITE FROM BUTTE COUNTY, CALIFORNIA

R. Scott Creely
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A pegmatitic rock from Butte County, California, consists principally of large crystals of pale-green amphibole and highly sodic plagioclase. The pegmatite grades into brecciated and schistose variants of almost identical mineral composition to that of the pegmatite.

The whole is enclosed in a narrow belt of serpentine which has been intruded into Upper Paleozoic sedimentary and volcanic rocks. Field and mineralogical evidence suggests that the pegmatite originated in depth and was carried passively up to its present position during the intrusion of the enclosing serpentine body.

GENERAL REFRACTIVE INDEX-SILICA CURVE FOR CALC-ALKALINE ROCKS

Garniss Curtis and Ralph I. Clark
Univ. Calif., Berkeley, Calif.

Indices of refraction of fused glass beads of 83 analysed specimens, representing 9 selected suites of calc-alkaline extrusive igneous rocks, have been used to establish a general refractive index-silica-content curve for artificial glasses of rocks ranging in composition from olivine basalt to rhyolite. The method of Mathews has been employed, and three of his published curves have been incorporated.

A mean departure from the curve of plus or minus 1.4 per cent silica for the 83 specimens, with a maximum of 5 per cent, indicates the degree of accuracy expected.

The technique involved as well as applications and limitations of the method are discussed.

BATHYGRAMS OF THE 1950 SCRIPPS-NAVY MID-PACIFIC EXPEDITION

Robert S. Dietz, H. W. Menard, and E. L. Hamilton
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Exclusive of the Mid-Pacific Mountains region, about 12,000 nautical miles of bathygrams (graphically recorded sea-floor profiles) were obtained between San Diego and the Marshall Islands on the MidPac Expedition. These profiles reveal the following:

(1) Thirty seamounts (isolated rises more than 3000 feet) were crossed. Most of these are newly discovered. Fourteen are higher than 5000 feet, and 6 are higher than 10,000 feet. A guyot with a truncated summit at 800 fathoms was discovered northwest of Midway. At least two of the seamounts appear to have "moats" around their base. The seamounts are considered to be of volcanic origin.

(2) Three ridged scarps were crossed—viz., the Mendocino Escarpment, 150 miles north of Bikini, and another 200 miles southeast of Hawaii. These ridged scarps mark abrupt changes in sea-floor level.

(3) Two swells—i.e., broad low regional rises of the sea floor about half a mile high and several hundred miles across—were discovered. The Hawaiian Islands are superposed on one of the swells, and the Mid-Pacific Mountains on the other.

(4) Three U-shaped depression (grabens?) were discovered.

(5) Between the U. S. and Hawaii the sea floor is mostly rough with few large seamounts. West of Hawaii there are numerous large seamounts and extensive flat basins. Using flat bottom as a criterion, sedimentary accumulation is taking place on only about one-third (37%) of the sea floor. Some process appears to be competent to move sedimentary detritus into the topographic lows on the deep sea floor.

DEEP-SEA CHANNEL OF THE MONTEREY CANYON

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A survey of the deep-sea floor beyond the base of the continental terrace off Monterey reveals that the Monterey Submarine Canyon (like the Hudson Submarine Canyon as described by Erickson, Ewing, and Heezen) connects onto a deep-sea channel of 100 fathoms relief which continues seaward

for at least 65 nautical miles across a broad low delta. Portions of this channel appear to be leveed. A core taken on the delta consists of uniform green terrigenous mud; another from the axis of the channel consists of terrigenous mud with fine-grained sand layers.

The channel is considered to be caused by turbidity currents which are initiated in the Monterey Canyon. The flows are below grade when they flow across the abyssal sea floor so that they build up a leveed channel by differential deposition.

Observations off California suggest that such deep channels associated with submarine canyons are not uncommon. However, Dietz has observed other channel-like notches on fathograms of the deep-sea floor, viz., in the Gulf of Alaska, in the Indian Ocean, and in the Atlantic. Some of these are far from the continental slope and have no apparent connection with submarine canyons.

STRATIGRAPHIC EVIDENCE CONCERNING THE THEORY OF PERIODIC DIASTROPHISM

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The theory of periodic diastrophism maintains that times of widespread diastrophism alternated with intervening quiescent times and that the magnitude and frequency of orogeny have increased with time.

Some stratigraphic evidence upon which the philosophy is based is equivocal:

(1) Classical realization of the incompleteness of the geologic record (a) involves the inevitability of having more and better information about late events, and (b) implies that early strata are apt to be incompletely preserved.

(2) Calculations based on thickness instead of volume are manifestly inadequate.

(3) Coarse sediments generally indicate relative uplift, but fines do not necessarily mean the opposite.

(4) Basing degree of downwarping on the thickness of accumulated strata, even in nearly landlocked basins, is frequently inadequate. Conversely, strata deposited as foreset beds are apt to be measured as a much greater stratigraphic thickness than actually accumulated in vertical section.

(5) Deposition of limestone not only does not necessitate quiescent periods, but must indicate uplift and possible orogeny somewhere. It is presumed that the ocean has been saturated with calcium carbonate since carbonate rocks became a conspicuous feature of the stratigraphic record. Therefore, extraordinary accumulations of limestone required source areas somewhere over and above those needed to maintain the saturation. If limestone is deposited near shore during uplifts, then about five times as much clastic material has to be moved offshore. The result is that the rate of vertical accumulation could be the same for both types of sediments.

AERIAL PHOTOGRAPHY AND THE AIRBORNE MAGNETOMETER IN OIL AND MINING GEOLOGY

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Aerial photography or the airborne magnetometer are being used in practically every country of geological importance.

In the oil industry aerial photography is indicated wherever surface geology is significant. Even where surface geology has no correlation with structural conditions, aerial photography is often used as the base map for geophysical compilation.

In mining, the applications of aerial photography are frequent but not quite so universal. While oil interest usually involves hundreds of miles, or thousands, mining interest is apt to be confined to 1 square mile or 10. The outstanding exception is the 11,000 square mile mining survey in Venezuela from which the Cerro Bolivar was discovered.

The airborne magnetometer is used in both oil and mining geology. During 1951 200,000 square miles within the United States were surveyed.

Mining applications include:

(1) Direct detection of very magnetic or relatively nonmagnetic ores (a large magnetite deposit in Pennsylvania)

(2) Indirect detection of other ores by:
  (A) Delineation of structural conditions (pre- and post-mineral faulting)
  (B) Delineation of igneous masses (porphyry coppers, kimberlite pipes; ore in contact-metamorphic relations)
  (C) Localization of possible igneous source (lead-zinc in Tri-State and Southwestern Wisconsin)
  (D) Discovery of customarily related rock types (magnetic shales associated with Witwatersrand gold gravels)

FORMATIONAL AND DRILLING CHARACTERISTICS OF CRETACEOUS ROCKS—"BIG BEND DISTRICT", TEXAS-MEXICO

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An extensive drilling program in connection with the "Upper Dams Investigation", along the Rio Grande, cored some 20,000 feet of predominantly Cretaceous sediments in widely spaced areas.

Information on formational units, contacts, and drilling characteristics was collected. The Boquillas, Del Rio, Walnut-Comanche Peak, Maxon, and Glen Rose (lower portion not penetrated) are in general argillaceous with a few calcareous units. There are sand units in the Maxon and Del Rio. The Kiamichi is somewhat more calcareous than argillaceous. The Buda, Georgetown, and Edwards are almost entirely calcareous with chert nodules common in the latter two.

Basal contacts of the Boquillas, Buda (where Del Rio is present), Del Rio, Edwards, Walnut-Comanche Peak, and Maxon formations are sharp and readily distinguished in the core on the basis of lithology. Basal contacts of the Georgetown and Kiamichi are gradational and based respectively on increasing and decreasing amounts of argillaceous matter. Where the Del Rio is absent, dense Buda overlies medium-grained Georgetown.

Bit penetration was generally rapid (3–6 minutes per foot), slowing somewhat in dense limestone and becoming very slow in chert. Drill-water loss increased with decrease in argillaceous material. Core recovery was excellent except in zones of solutioning and faulting. "Pumping in" tests on core and water-loss zones were made to obtain transmissability data.

Abundant small fossils in the Del Rio (*Exogyra arietina* and *Haplostiche texana*) and Glen Rose (*Orbitolina texana*) together with small curved calcite veins in the Buda were important horizon markers.

OCCURRENCE OF GROUND WATER NEAR FLAGSTAFF, COCONINO COUNTY, ARIZONA

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Ground-water investigations in the area extending about 15 miles east and 15 miles west of Flagstaff, Arizona, indicate that a rectangular drainage pattern reflects northeast- and northwest-trending joint sets. Major faults trend north and probably act as channels for ground-water flow. Northwest-trending branch faults and joints,[1] some occupied by basalt dikes, probably account for a difference in elevation of 2000 feet between the levels at which ground water emerges in Oak Creek and in Sycamore Canyons, 15 miles apart.

Deep canyons along the Mogollon Rim act as drains and thus lower the water table. One well 12 miles west of Flagstaff yields 30 to 50 gallons per minute between 1270 and 1650 feet in the Supai formation of Carboniferous (Pennsylvanian) and Permian age. Overlying strata were dry except for 5 gallons per minute in the uppermost 65 feet where the well tapped water perched in clay and gravel. East of Flagstaff, the deepest test was drilled to 410 feet in the Permian Kaibab limestone, and was dry.

Perched water at depths of 4 to 200 feet occurs commonly in unforested areas west of Flagstaff in Tertiary to Recent clay, gravel, and basalt. East of Flagstaff, fewer than 10 wells have yielded water. Only one is now in service.

Springs west of Flagstaff yield 1 to 100 gallons per minute at basalt-soil contacts. Yields of the six

known springs east of Flagstaff, excluding those on San Francisco Peaks, are less than 10 gallons per minute.

A shaft sunk east of Flagstaff encountered "fossil ice" estimated to be 600 to 1000 years old, preserved in an abandoned Indian walk-in well.

SEDIMENT TRAP STUDIES OF SAND MOVEMENT IN LA JOLLA BAY

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Observations of sand movement in La Jolla Bay were made using a multi-sock sediment trap designed to separate the onshore, offshore, and longshore components of sediment transport. Divers equipped with Aqua-lungs checked the operation of the trap at all stations. Median diameters of sediments collected on the gently sloping shelf out to a depth of 85 feet show a decrease away from shore. At each station the sediments in the bags show a progressive decrease in equivalent grain size with increasing height above the bottom, although this tendency is less marked at depths of more than 40 feet. Weight of sediment caught per hour at a given bag height above the bottom plotted against orbital velocity, computed from wave theory, indicates that a small increase in maximum orbital velocity results in a great increase in amount of sediment transported. At depths shallower than 45 feet nearly all sand movement occurs as an intermittent sheet flow extending only 15–25 centimeters above the bottom and moving alternately in the onshore and offshore directions.

Sands caught by the trap in the shallow head of Scripps submarine canyon have a decidedly higher mica content than those from like depths on the open shelf under similar wave conditions. Mud was present in small quantities in samples taken in the canyon during a heavy rainstorm, but there was no evidence of increased sand transport under these conditions.

SEDIMENTATION AND OROGENY, WITH PARTICULAR REFERENCE TO THE GULF COAST GEOSYNCLINE

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Sedimentation in the Gulf Coast geosyncline has been a continuous process; since early Mesozoic time 25,000–40,000 feet of deltaic and shallow marine deposits have accumulated. As sediments were deposited, the geosyncline was progressively downwarped, and its axial position shifted seaward concurrently with slight, but continual, uplift of its inland limb. Post-Lower Cretaceous deposits record cycles of sedimentation during the Upper Cretaceous, Eocene, and late Tertiary-Quaternary. Each cycle opened with an influx of terrigenous sediments, reached its peak at times of maximum delta outgrowth, and closed with diminishing sedimentation and the advance of a shallow sea across former deltaic plains. Peaks were reached during the lower Upper Cretaceous, Lower Eocene, and Mio-Pliocene (or Quaternary), and reflect rejuvenation of streams, thus indicating times of epeirogenic uplift. Centers of deltaic deposition were areas of thickest accumulation and maximum downwarping during a given cycle. The widely separated positions of the deltaic centers of different epochs point to major drainage changes and demonstrate the control exerted on geosynclinal downwarping by sedimentary load. Glacio-eustatic shifts in sea level and the introduction of Mississippi River sediments for the first time during the Quaternary complicate the last cycle. Thick deltaic Mio-Pliocene deposits, found in deep borings made in the Mississippi deltaic plain close to the continental slope, indicate that delta fronts once extended beyond the present continental shelf and suggest that the Gulf was a comparatively shallow sea until the Quaternary, when faulting may have formed the existing continental slope and Sigsbee Deep.

UNIQUE BURIED PLEISTOCENE LAKE DEPOSIT IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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An important clay bed, initially distinguished and singled out for study in the vicinity of Corcoran, California, is presented as a member in the upper Tulare formation, and is apparently of mid-Pleisto-

cene age. It is 300 to 800 feet deep throughout hundreds of square miles, with a thickness of 50 to over 100 feet. A high diatom content, low specific gravity, and an included rhyolitic ash bed distinguish it from other clays in the section. A remarkably low percentage of sand-size grains is characteristic, and the electric-log pattern is distinctive. The member reflects some important deep structures, and its hydrologic properties are significant to ground-water developments, especially along the west side of the valley.

CONSTRUCTION GEOLOGY OF TUNNEL NO. 12, S. P. R. R.: RELOCATION AROUND SHASTA DAM RESERVOIR, CALIFORNIA

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Tunnel No. 12 was constructed for the U. S. Bureau of Reclamation in relocating the Southern Pacific Railroad around Shasta Lake in the Klamath Mountains of Northern California. The tunnel was driven through a section of indurated Mississippian conglomerates, sandstone, and shales, overlain, in the northern half of the tunnel, by compact but unconsolidated stream gravels capped by hard but blocky basalt flows of Pleistocene age. The contact between the gravels and the basalt is irregular and lies within a few feet above and below the roof of the tunnel. Tunnelling conditions depended on details of the gravel-basalt contact and on the character of the bedrock. These, and the construction methods necessitated by them, are discussed.

URANIUM DEPOSITS OF THE WHITE SIGNAL DISTRICT, NEW MEXICO

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Uranium minerals were found in the White Signal district, New Mexico, in 1920. Recent work by the U. S. Geological Survey on behalf of the Atomic Energy Commission has extended the area of known occurrences, and now 74 radioactive deposits are known within an area of 60 square miles.

The country rock is largely granite intruded by dikes of different ages and compositions. The older dikes—diabase and basalt—characteristically trend northwest; the younger dikes—diorite, dacite, quartz monzonite, latite, and rhyolite—have trends ranging from northeast to east. Faults containing copper- and gold-bearing quartz-pyrite veins cut both the granite and the dike rocks.

The uranium minerals identified are the secondary phosphates autunite and torbernite. For the most part, they occur in fractures and as disseminations within the mafic and intermediate dikes. In a few places, autunite and torbernite coat fractures in the granite. The uranium minerals are related spatially to the quartz-pyrite veins, and it is believed that a study of the quartz-pyrite veins and of the dikes is essential to our understanding of the distribution and character of the uranium deposits. Primary uranium minerals may have been present originally in these veins, and possibly they still exist below the zone of oxidation. Near the surface, however, acid-rich solutions have dissolved the primary uranium minerals and have deposited the uranium in the form of autunite and torbernite in the vicinity of the phosphate-rich mafic and intermediate dikes.

CONNECTION BETWEEN OROGENY AND EPEIROGENY AS DEDUCED FROM THE HISTORY OF THE COLORADO PLATEAU AND GREAT BASIN*

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In Cretaceous time the Colorado Plateau stood essentially at sea level; its broad expanse and simple structure suggest a close approach to isostatic equilibrium. Various parts were later differentially loaded by sediments and differentially eroded. Assuming continued isostasy this differential loading should result in differential warping of any older structural datum.

Rough computations from various areas suggest that actual warping does broadly accord with that expected on the isostatic hypothesis. But both structural basins and swells are 4000 to 6000 feet higher than they should be if sedimentation and erosion were the only factors involved.

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This uplift thus cannot reflect surficial processes; it is due to changes within or beneath the crust. It conforms to what would be expected if the entire crust were thickened about 4 or 5 miles. It may possibly be attributed to thermal expansion, partial melting, or other phase changes within the crust, to lateral transfer of sial from outside into the region, or to accumulation in a relatively shallow layer of sial squeezed from a thick zone of the mantle. Lateral flowage of hypothetical mountain roots from the peripheral ranges seems wholly inadequate to supply the great volume required on the assumption of sial thickening. Possibly subcrustal currents carrying in sial to accumulate below the plateau are implied. Such flowage, by adding to the regional radioactivity, might also contribute to any thermal expansion that may have occurred.

The problems of epeirogeny seem so similar to those of orogeny as to suggest a common cause.

GROUND-WATER RESOURCES OF THE NAVAJO AND HOPI INDIAN RESERVATION, ARIZONA, NEW MEXICO, AND UTAH

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The Ground Water Branch of the United States Geological Survey is engaged in a study of the ground-water resources and geology of the Navajo country, which lies in northeastern Arizona, northwestern New Mexico, and southeastern Utah.

The occurrence of ground water in the region is dependent on the dominant factors of topography, climate, stratigraphy, and structure. The Navajo country consists of deep canyons and high mesas, displaying sharp relief. Runoff is rapid, and in places the rain and snow melt do not contribute much recharge to aquifers. The climate is arid and is characterized by extremes of temperature and rainfall. The average precipitation is 10 inches per year. The prominent geologic structures are gently dipping synclines, anticlines, and monoclines, which are of first importance in relation to the occurrence of water. The inadequate water supply has a dominant effect on the economy of the region.

The principal aquifers of the region are the Permian sandstones, the Triassic Shinarump conglomerate, the Jurassic (?) Navajo sandstone, the Jurassic Cow Springs sandstone, the Cretaceous Dakota sandstone, and the sandstone members of the Cretaceous Mesaverde formation. Quaternary alluvium yields water to wells in some places, but in most places these supplies are subject to failure in time of drought.

Many more wells can be drilled for livestock and domestic use without overdeveloping the principal aquifers. There is little possibility for developing ground-water supplies for irrigation, except limited quantities from the alluvium in the few places where recharge is abundant.

UPPER CRETACEOUS, TERTIARY, AND RECENT PLANKTONIC FORAMINIFERA FROM MID-PACIFIC FLAT-TOPPED SEAMOUNTS

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Foraminifera were collected by the 1950 Scripps Institution-Navy Electronics Laboratory Mid-Pacific Expedition. Five flat-topped seamounts (*guyots* of Hess, 1946) were dredged and cored in an area between 600 and 1100 miles west of Hawaii.

The following faunas have been identified:

Basaltic gravel layers in a core at 2050 fathoms near one of the guyots contain an Upper Cretaceous (Campanian-Maestrichtian) fauna including species of *Globotruncana*, striate *Gümbelina*, and *Ventilabrella*, mixed with Tertiary and Recent species.

An Upper Paleocene fauna dominated by *Globorotalia velascoensis* occurs in indurated globigerina ooze on top of a second guyot.

Two cores taken on top of another guyot contain a Lower-Middle Eocene globogerina ooze planktonic assemblage dominated by *Globorotalia aragonensis* and with *Hantkenina mexicana* to within an inch of the top of the core.

Conclusions are that the mixed Cretaceous-Recent fauna and the gravel were transported by turbidity currents to their present location and that the Eocene ooze on top of one guyot is due to nonaccumulation of later planktonic sediments.

The Foraminifera date the truncation of one guyot as pre-Upper Cretaceous and two others as

pre-Paleocene-Eocene which generally supports the evidence provided by the "Middle" Cretaceous reef coral-rudistid fauna dredged from two guyots.

Geographic ranges of many Upper Cretaceous and Tertiary planktonic index species have now been extended into the middle Pacific. These forms will be useful in dating and solving problems of the sedimentation of deep-sea sediments.

OCCURRENCE OF HELIUM IN NORTHEASTERN ARIZONA

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Helium gas is reported from a well drilled to 1520 feet 40 miles northeast of Holbrook, Arizona. The well is located at an elevation of 5830 feet on the crest of a broad dome in the Black Mesa basin.

The well began in mudstone of the Chinle formation (Triassic). Successive formations were: Shinarump conglomerate (?) (Triassic) at 855 feet, Moenkopi formation (Triassic) at 890 feet, Coconino sandstone (Permian) at 1030 feet, and Supai formation (Permian) at 1415 feet. Identification of the Shinarump conglomerate is tentative. Contact between the Coconino sandstone and the Supai formation appeared sharp.

A small amount of gas flowed from sandstones within the Chinle formation at about 720 feet. The main gas flow was struck at 1032 feet, 2 feet below the top of the Coconino sandstone, and the flow appeared to increase with depth through the Coconino. The gas pocket in the Chinle formation is believed to have been leakage from the Coconino sandstone.

Four weeks after the well blew in the flow was 24,000,000 CFD, and the shut-in casing head pressure was 98 psi. The gas was noninflammable and contained salt-water vapor. Analysis showed: Helium, 8.09%; Nitrogen, 89.08%; Hydrocarbons, 1.23%; Carbon Dioxide, 0.91%; other constituents, 0.69%.

Helium has limited commercial value at this time. The well flowed freely for about 8 months before being capped. The volume of flow appeared to decrease as a result of the unrestricted flow, but no further measurements were made.

ORIGINAL LOWER COURSE OF RUSSIAN RIVER, CALIFORNIA

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Russian River joins the Pacific Ocean 60 miles northwest of San Francisco. Several writers have suggested that long ago the lower part of the river was displaced from a more suitable southeastward course through Santa Rosa-Petaluma Valley into its present anomalous westward course incised into the coastal highlands.

However, closely spaced straight westward transverse courses of four streams south of Russian River suggest that they originated as "extended" streams—*i.e.*, their headwaters originally lay in the mountains east of Santa Rosa Valley, and their lower courses were simply extended westward across newly emergent Pliocene Merced formation sediments as the Merced sea retreated. During Pleistocene time the headwaters of these streams were cut off, and part of one of the streams was reversed due to the creation of Santa Rosa-Petaluma Valley by subsidence. The southernmost stream probably lost its headwaters only after completion of the "one hundred foot" marine coastal terrace; thus the older, higher stream terraces in Russian River Canyon show that Russian River occupied its present course prior to the existence of a possible route to San Francisco Bay via Santa Rosa-Petaluma Valley.

This suggests that Russian River has, since its inception, occupied essentially its present transverse lower course, having very likely acquired it by extension across and superposition from a mantle of Pliocene Merced sediments of which, unfortunately, no trace remains in the canyon vicinity.

ANORTHOSITE IN THE SAN GABRIEL MOUNTAINS, SOUTHERN CALIFORNIA

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The anorthosite and related rocks are a part of the crystalline complex of the San Gabriel Mountains. Within the area studied (about 50 square miles of the western part of the range) the rocks are

separated into three groups: (1) metamorphic rocks, (2) norite-anorthosite complex, (3) quartz diorite and biotite-muscovite granite.

The norite-anorthosite complex is a domelike intrusive in metamorphic rocks and is separable into three rock types: with norite at the margin of the intrusive, grading through transition rock to the anorthosite core. Characteristic features of the complex are: (1) irregular banding, (2) poikilitic texture, particularly in the transition rock, (3) giant grain size, (4) uniform plagioclase composition and lack of zoning, and (5) uniform shattering of the intrusive complex.

The parent magma of the norite-anorthosite complex was noritic in composition. Crystallization of hypersthene and plagioclase began with falling temperature and was long continued under very uniform conditions. Hypersthene began to crystallize before plagioclase, but most of it crystallized with plagioclase; plagioclase continued to crystallize long after hypersthene had ceased to crystallize. The magma, residual after hypersthene crystallized, was rich in water, potash, iron, titanium, and phosphorus. Plagioclase crystallized from this magma to form the anorthosite. The complex was uniformly shattered prior to deuteric and hydrothermal alteration.

ANALYSIS OF THE STRATIGRAPHY IN THE LOWER KUSKOKWIM REGION, ALASKA

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Reconnaissance mapping of an area of about 11,000 square miles in the Lower Kuskokwim region, Alaska, has revealed information on the age, nature, and geologic history of the rocks of a little-known area. The rocks range from Precambrian (?) to Pliocene or Pleistocene.

Rocks of probable Precambrian age consist of gneiss and schist formed by the metamorphism of sedimentary and volcanic rocks.

Rocks of early Paleozoic age are largely limestone. They indicate a lack of orogeny during early Paleozoic time.

The Permian and Triassic periods are represented by fine-grained clastic rock, chert, volcanic rock, and limestone, which were deposited under nonorogenic conditions and were derived from local submarine and subaerial volcanism and from a distant terrestrial source.

Formations of Upper Jurassic (?), Lower Cretaceous, and middle Upper Cretaceous ages contain a large amount of coarse sandy to conglomeratic sedimentary rock, a lesser amount of fine-grained sedimentary rock and basic lava, and a minor amount of limestone. The coarse clastic rocks were derived locally from one or more geanticlines, which probably first arose in Middle or Upper Jurassic time and were rejuvenated in late Lower Cretaceous time. The conglomerate that resulted from the rejuvenation of the geanticlines is thought to be of Lower Cretaceous age rather than early Upper Cretaceous age.

CALDERAS OF THE PINACATE REGION, SONORA, MEXICO

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The rough surface of the great Pinacate lava fields, in northwestern Sonora, is punctured by seven large calderas that contrast sharply with the many volcanic cones in the region. The main caldera group is at the north end of the Pinacate Range, about 15 miles south of the International Boundary; two other, isolated calderas lie farther east and southeast.

The largest of these collapse depressions is Crater Elegante, which is steep-walled, nearly circular in plan, about a mile in diameter, and 800 feet in maximum depth. Its development, late in Quaternary time, evidently centered about a complex group of vents from which basalt flows and thick but lenticular accumulations of cindery ejecta had been derived previously. The eruptive activities reached a climax when a single large cone was rapidly built with bombs, lapilli, and vast quantities of basaltic froth. Almost immediately thereafter, the cone collapsed into the large chamber whence its materials had come. For a time the caldera thus formed was occupied by a lake, into which a narrow delta was built.

Essentially the same sequence of events appears to have preceded formation of the other calderas. In none of these others, however, is there evidence for the existence of a temporary lake.

Caldera development probably was the result of ultravesiculation, or the "flashing off" of dissolved gases from shallow chambers of magma during the period of cone building. This resulted in construction at the surface, concomitant removal of support from beneath, and prompt, large-scale collapse.

TERTIARY VOLCANICS AND ASSOCIATED ROCKS OF THE LAKE VALLEY AND SHERMAN QUADRANGLES, SIERRA, GRANT, AND LUNA COUNTIES, NEW MEXICO*

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The Tertiary section in the Lake Valley and Sherman quadrangles in southwestern New Mexico, southeast of the Santa Rita area, consists for the most part of andesites, latites, quartz latites, rhyolites, and their fragmental equivalents. Fanglomerate and lacustrine deposits have been found in the sequence.

The earliest effusives are andesites and andesitic tuffs and breccias, disconformably overlain by latites. Erosion of the latites yielded a very irregular surface on which rhyolite tuffs were deposited, later to be followed by rhyolite and quartz latite welded tuffs, additional rhyolite tuffs, and rhyolite flows. Some of the rhyolite is intrusive. Perlite and pitchstone are associated with rhyolite flows and intrusives. In the Sherman quadrangle an erosional interval, marked locally by the deposition of sands, gravels, and fanglomerates, separates this earlier rhyolitic phase from later rhyolite flows, breccias, and tuffs followed by basaltic andesite flows and breccias.

The volcanic sequence is capped by the Santa Fe formation (Miocene-Pliocene), which consists chiefly of fanglomerates but includes calcic latites, and agglomerates. Partly dissected Pleistocene terrace gravels and pediment gravels cover portions of the area.

No relation other than a faulted contact has been found between the Cooks Peak granodiorite plug (post-upper Cretaceous) and the volcanics, though in other areas, such as Silver City, the lower or andesitic volcanics are intruded by granitoid rocks.

Lead-zinc-silver and copper veins occur in the early andesites.

Petrographic work on the various rock types is correlated with chemical analyses.

POST-LARAMIDE STRUCTURAL AND VOLCANIC TRENDS IN NEW MEXICO

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Interpretation of controlled photomosaics of New Mexico reveals a region of numerous Quaternary fractures, bounded on the northwest by a straight belt of late Cenozoic volcanic vents, on the east by an irregular line of west-facing scarps. This fractured region lies within Colorado Plateau and Basin and Range provinces.

The volcanic belt is up to 15 miles wide and contains nearly 100 central vents. It trends N. 37° E. for 200 miles from Springerville, Arizona, across the Datil Section of the Colorado Plateau, includes the volcanoes of Mt. Taylor field and of Jemez caldera, and ends on the lava plain near Cuesta. Fifty miles northeast, Spanish Peaks in Colorado are in line with this belt.

The series of west-facing scarps extends northward from Texas along the east side of Tularosa Valley, west sides of Chupadera Mesa, Manzano Mountains, Glorieta Mesa, and the Truchas Range.

Within these boundaries, upper Tertiary dikes and Quaternary faults and aligned volcano clusters present a strain pattern which would result from north-south compression along a Rio Grande-Jornada del Muerto structural axis. Predominant strike of fractures east of the axis is north-northeast; near the axis, north; west of the axis, north-northwest. Accordance of dike trends with this pattern indicates pre-Quaternary initiation of the pattern. Over 5000 miles of reconnaissance and examination of 65 published and unpublished geologic maps have shown few major fractures and dikes outside the area; those observed are pre-Quaternary and not parallel to pattern trends.

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PRE-NIOBRARA CRETACEOUS STRATIGRAPHY OF CASTLE VALLEY, UTAH

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Castle Valley is between the Wasatch Plateau and the San Rafael Swell in east-central Utah. For 80 miles along the east side of the valley there is a continuous line of northeast-southwest exposures of Upper Cretaceous rocks which show evidences of an ancient oscillating shore line. The time relations of the near-shore sediments of the southwest to the offshore deposits of the northeast were determined with the aid of fossils, particularly the ammonites. Detailed plane-table mapping by the writer revealed rapid lateral facies changes.

The pre-Niobrara Cretaceous rocks of Castle Valley include, in ascending order, the Buckhorn conglomerate (Lower Cretaceous?), Cedar Mountain shale, Dakota sandstone, Tununk shale member, and the Ferron sandstone member of the Mancos shale.

The upper part of the Cedar Mountain shale at its type locality near Castle Dale, Utah, contains the fresh-water pelecypod *Eupera onestae* which is Lower Cretaceous (Aptian) in age.

The Dakota sandstone of Castle Valley is assigned an Albian age on the basis of the occurrence of *Inoceramus comancheanus* in the middle part of the formation.

The Tununk shale member and the Ferron sandstone member of the Mancos shale contain successive faunas like those of the Graneros shale, Greenhorn limestone, and the Carlile shale of the standard Cretaceous section of the northern Great Plains.

ENGINEERING GEOLOGY OF THE "UPPER DAMS INVESTIGATIONS"—INTERNATIONAL DEVELOPMENTS ALONG THE RIO GRANDE

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The "Upper Dams Investigations" by the International Boundary and Water Commission required geologic mapping of a strip 4–15 miles wide athwart the Rio Grande between Lajitas and Del Rio, Texas; some 26 potential sites were investigated.

Cretaceous limestones and argillaceous rocks are predominant. Older formations—Glen Rose, Maxon, Walnut-Comanche Peak, Edwards, and Kiamichi—are most prevalent upstream; younger formations—Georgetown, Del Rio, Buda, and Boquillas—are widespread downstream. Deep, narrow canyon sites abound in the Mexican Highlands; graben or synclinal valleys separate northwest ranges. Northwest faults (Del Carmen Mountains) are apparently seismically active. Sites are broad and low in the Edwards Plateau; the river roughly parallels the axis of a broad syncline.

Cored borings (43) assisted in determining: thickness; lithology; relative transmissibility rates; and the zone of saturation by subsurface waters, supplemented by well soundings and geophysical data.

Solutioning has developed sinkholes and irregular, partially integrated openings. "Base levels of solution" are inherent above stream grade. Reservoir sites include four combinations of permeable and impermeable strata; at some, circuitous leakage would occur. Locally, ground water appears to be a "skeletonized" system in structures.

Foundation rocks are adequate at most dam sites; thin interbeds of shale and argillaceous limestone and solutioned rocks will require special treatment.

Earth-fill deposits are scarce, except in the intermontane valleys and near Del Rio. Natural aggregate deposits occur locally. Aggregates, rock fill, and rip-rap can be manufactured by quarrying the Georgetown, Buda, or upper Boquillas formations.

A high concrete dam (upstream) and earth-fill (downstream) are planned (Ainsworth, 1951) as initial developments.

STRUCTURAL LOCALIZATION OF GROUND WATER IN LIMESTONES—"BIG BEND DISTRICT", TEXAS-MEXICO

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Ground-water studies throughout parts of the "Big Bend District" were completed by the International Boundary and Water Commission in connection with future developments along the

Rio Grande. Cretaceous limestones are predominant and the major source of ground water. The Edwards limestone, principal aquifer, is overlain by the impervious Kiamichi formation; also favorable structures result in significant production from the younger Georgetown limestone.

The "District" consists of: asymmetrically folded and faulted rangr separated by valleys in the Mexican Highlands; and an ovaloid basin of low-dipping beds interrupted by asymmetrical, northwestward-trending flexures in the Edwards Plateau. Major springs issue along northwestward-trending faults in the "Highlands" and along northeastward-striking breaks in the "Plateau".

Solutioning, primarily structurally controlled, is a major factor in ground-water movement. Cored borings confirmed this hypothesis and indicated that faults acted both as "barriers" and "avenues". Initial development of solutioning apparently began in middle to late Tertiary time.

Sinkholes as recharge "avenues", particularly in the "Plateau", are associated with the crests and troughs of flexures and the intersection of faults, shears, and joints.

Wells located on "highs" and "lows" of flexures produce from the shallower Georgetown limestone; interconnected openings have apparently developed due to fracturing, thereby facilitating recharge. In addition, deeper wells produce from the Edwards limestone.

Where the Del Rio clay is absent, the solutioned upper part of the Georgetown limestone is potentially a good water producer.

Regionally, the direction of underground flow is normal to the Rio Grande with a parallel and oblique movement locally.

URANIUM IN METAL-MINING DISTRICTS OF COLORADO

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The most favorable ground in Colorado for uranium ore deposits, exclusive of the Colorado Plateau, is the Central Mineral Belt. Here potentially important uranium deposits occur in metalliferous veins in Precambrian igneous and metamorphic rocks, usually in association with Tertiary intrusives. The deposits also occur in Paleozoic and Mesozoic rocks that surround the Precambrian core.

The uranium deposits of Colorado may be classified into eight types: (1) disseminations in sedimentary rocks, (2) veins, (3) replacement deposits in limestone, (4) volcanic breccia pipes, (5) disseminations in igneous and metamorphic rocks, (6) pegmatites, (7) radioactive inclusions in rhyolite, and (8) hot-spring deposits. Disseminated carnotitelike minerals in sedimentary rocks constitute the important uranium deposits in the Colorado Plateau; vein-type deposits are the most important in the metal-mining districts.

Pitchblende is the most common uranium mineral in the vein type of deposit. In Colorado, pitchblende has been found in six types of veins: (1) pyritic gold-quartz veins, (2) lead-zinc-silver veins, (3) fluorite veins, (4) telluride veins, (5) pyrite-siderite-quartz veins, and (6) polymineralic hydrocarbon veins.

Detailed studies have shown that several geologic guides are useful in prospecting for new deposits. The most important of these are: (1) stratigraphic position, (2) mineral associations, (3) sedimentary structure, (4) rock alteration, and (5) regional zoning.

In addition, the following relations may be useful: (1) Uranium deposits are commonly associated with post-Cretaceous volcanism, (2) uranium is commonly found in metal-mining districts that have produced silver, lead, and copper, (3) accumulations of radon and helium theoretically are related to deposits of uranium, (4) many uranium deposits are associated with bostonite dikes, (5) uranium deposits seem to occupy a definite place in some types of hypogene zonal patterns, and (6) the colors of purple fluorite and smoky quartz are believed to be related to radioactivity.

PRECAMBRIAN ROCKS IN THE SANGRE DE CRISTO MOUNTAINS NEAR SANTA FE, NEW MEXICO*

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Precambrian metamorphic, igneous, and migmatitic rocks constitute the western flank and core of the Truchas Range of the Sangre de Cristo Mountains east of Santa Fe. Pennsylvanian, Permian?

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and Tertiary sediments and extrusives overlie the Precambrian rocks in the foothills and border the range on the west. The Precambrian rocks in the Seton Village and Santa Fe 7½-minute quadrangles are intimately faulted, sheared, brecciated, intruded *lit-par-lit*, and in places thoroughly altered and weathered. Breccia-, shear-, and fault zones outline the structural units in the area which trend north-south and northwest-southeast. Some of the breccia zones are pre-Pennsylvanian, but faulting post-dates the Tertiary Santa Fe formation.

A series of quartzites, mica schists, orthoclase-quartz-biotite schists, and hornblende-plagioclase schists is the oldest. *Lit-par-lit* injection of the schists adjacent to gray quartz monzonite dikes, sills, and stocks yielded a gray muscovite gneiss with contorted foliation. These schists and gneisses are cut by hornblende-biotite metadiorite that in places is schistose. Pink microcline granite which intruded the older rocks was probably the source of quartz-microcline-albite-muscovite pegmatites, pink aplite dikes, tourmaline-bearing quartz veins, and the few lamprophyric dikes. Injection of the granitic magma, especially of the more liquid phases, formed *lit-par-lit* gneisses and migmatites from the older rocks. Masses of the metadiorite adjacent to granite are changed to greenstone. Ptygmatic folds are prominent in the migmatites and injection gneisses. Hornblende schists and the metadiorite are locally epidotized near pegmatite and aplite dikes.

CONTROL OF TRACE-ELEMENT CONCENTRATIONS IN SEA WATER

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For most trace elements, the amounts dissolved during weathering of igneous rocks throughout geologic time are much greater than the amounts found in the present oceans. This suggests that sea water should be approximately saturated with these elements. Experiments designed to test this suggestion have shown that for many elements sea water is very far from saturated, and calculations of theoretical solubilities bear out the laboratory results. Experimental work has been limited to compounds made up of trace elements and the more abundant ions of sea water, because calculation shows that other ions in normal aerated sea water are present in amounts too small to precipitate the trace elements.

Control of concentrations below the saturation values may be exerted by many factors, of which the most effective are probably: (1) adsorption of trace-element ions on clay or organic matter; (2) high pH values in some parts of the ocean, causing local precipitation of compounds that are soluble in normal sea water; (3) unusually high local concentrations of less common ions like sulfide, iodide, or phosphate, which would form precipitates with the trace elements; (4) use of trace elements by living organisms. All these processes are known to affect some elements, but whether any one of them or some combination can be wholly accountable for the observed concentrations is still uncertain.

CENOZOIC GEOLOGY OF THE PRESCOTT QUADRANGLE, ARIZONA

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Sedimentary deposits and intercalated lava flows of Pliocene (?) age, Pleistocene pediment gravels, and Recent alluvium and river wash are exposed in the northern three-quarters of the Prescott quadrangle, in central Arizona.

The Pliocene (?) sedimentary deposits and lava flows within the Prescott quadrangle accumulated to a known thickness of 1300 feet, but the maximum thickness was probably at least 2000 feet. They accumulated in a northwest-trending basin of unknown origin and on a surface of considerable relief. The Pliocene (?) rocks consist of fanglomerate interfingered with beds of sand, silt, clay, and tuffaceous sediments, and with basaltic and andesitic flows. Cinder cones were formed and buried during the deposition. The sedimentary deposits are lithologically similar to beds 20 miles south of Prescott, which contain a lower Pliocene vertebrate fauna, and to the Gila conglomerate in southeastern Arizona, which is in part of upper Pliocene age. Fossil bones found in the deposits in the Prescott area are too fragmentary and immature to be diagnostic.

Although the eastern margin of the basin was uplifted along high-angle normal faults after basin filling, the present surface of the broad Lonesome and Chino valleys is one of erosion, and not of

valley filling. Erosion during Pleistocene time removed the upper part of the Pliocene (?) fill, developing a broad, gravel-strewn pediment that covered most of the quadrangle. This pediment was extensively dissected by Recent erosion.

ENDOMORPHIC EFFECTS OF XENOLITHS IN VOLCANIC GLASS

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A Tertiary tuffaceous rhyolite of the Black Range, New Mexico, includes a xenolith zone characterized by abundant fragments of an earlier quartz latite tuff unit and irregular masses of rhyolite vitrophyre. The tuff xenoliths in the vitrophyre are enclosed by a concentric rim of the devitrified rhyolite, and the sizes of rim and xenolith are related by a parabolic function. Identical fractured, corroded, and embayed phenocrysts of quartz, sanidine, plagioclase, biotite, and hornblende are present in the rim and vitrophyre. The devitrified rim matrix consists of quartz and soda- and potash-rich sanidines. Devitrification has produced a geochemical culmination in silicon and potassium and a depression in calcium, titanium, magnesium, aluminum, and iron. Here, crystallization of the rim is a result of the operation of the reaction principle, where the rhyolitic melt could crystallize through the exothermic reaction with the more basic quartz latite tuff xenolith. Inequilibrium has produced the chemical differences. The stability of possible mineral phases is the dominant factor causing the chemical differences by any mechanism of material transport.

LATE QUATERNARY FOSSILS NEAR TUCSON, ARIZONA

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Deposits about 10 miles south of Tucson, Pima County, Arizona, contain fragmentary fossil remains, including a complete lower molar tooth of an advanced species of *Equus* and tooth fragments of a camel. Included in these deposits are also artifacts typologically related to the Sulphur Springs stage of the Cochise culture. The artifacts have been found within 10 feet stratigraphically above the fossil-bearing horizon.

The beds consist largely of nodular marls, with limestones, silts, and thin sand and pebble conglomerate lenses. They have been exposed, according to local reports, within the last 10 years by headward erosion of a small arroyo tributary to the Santa Cruz River. The sequence of marls is overlain by at least two younger sedimentary units—a dark silty clay and younger flood-plain deposits. The flood-plain sediments were laid down on an irregular surface cut into the marls and dark clay. The dark clay contains artifacts representing stages in the Cochise culture later than the Sulphur Springs stage.

An extinct mammalian fauna is associated with Sulphur Springs artifacts at other localities in southeastern Arizona. The fossils of the Santa Cruz locality appear to be somewhat younger than those of the Curtis Ranch Pleistocene of the San Pedro Valley.

HEMATITE VEINLETS IN AN IGNIMBRITE IN THE IRON SPRINGS DISTRICT, SOUTHWESTERN UTAH

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An early Tertiary volcanic sequence in the Iron Springs district includes true flows, air-fall tuffs, and breccias, but is made up predominantly of units formed by eruptions of the *nuée ardente* type. The ignimbrite units fall within the latite-rhyolite compositional range. Some of the units are non-welded or only slightly welded, some are welded only at the base, and some are thoroughly welded from base to top.

The thickest of the completely welded ignimbrite units consists of a basal black vitrophyre (12′ ± 8′); a middle reddish-purple lithoidal unit characterized by a pronounced compaction foliation (120′ ± 30′); and an upper purplish-gray nonfoliated lithoidal unit (30′ ± 10′). The contrast between the lustrous basal glass and the lithoidal portions is due chiefly to devitrification. Although somewhat intergradational, the three units are mappable over hundreds of square miles.

Veinlets of crystalline hematite occur in joints and minor breccia zones in the upper lithoidal unit at a number of localities. Field relations rule out the possibility that the veinlets were formed by solutions rising from depth through subjacent sedimentary and volcanic rocks. It seems inherently unlikely that the solutions could have been carried forward within the *nuée ardente*. These considerations, and other evidence, favor the hypothesis that the solutions originated within the unit after it came to rest.

Reaction borders around mafic "phenocrysts" in the lithoidal portions suggest that the iron may have been released by endomorphic decay of mafics during the consolidation and devitrification of the ignimbrite.

LATE CENOZOIC GEOLOGIC HISTORY OF THE TEMECULA REGION, SOUTHERN CALIFORNIA

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The Temecula region (a portion of the Elsinore fault zone) includes chiefly the Temecula and Aguanga basins, occupying downfaulted blocks of a Mesozoic basement complex on which late Cenozoic continental sediments have been preserved.

During the Pliocene the Temecula region was a broad alluvial surface with many *Inselberge*. At about the end of the Pliocene or very early in the Pleistocene, basalts were extruded over large areas on this surface. Closely following these extrusions the first important movements along the Elsinore fault zone occurred. Arkosic sediments were deposited in the early Pleistocene by streams flowing southwest from the vicinity of San Jacinto Mountain.

In the middle Pleistocene another broad alluvial surface was broken by great vertical movements of the Pasadenan orogeny; the Elsinore-Temecula trough was formed. Great exhumation of bedrock surfaces accompanied this uplift, and its progress is marked by several broad erosion surfaces and numerous terraces. The Santa Ana River developed a subsequent tributary down the Elsinore-Temecula trough and captured the San Jacinto and Temecula rivers. The older fanglomerates were deposited. Then a stream eroding headward at Temecula Canyon captured the drainage of the Temecula region. Following a short period of faulting the younger fanglomerates were deposited. In very late Pleistocene time nepheline basalts were erupted during two periods of volcanism separated by several hundred feet of erosion. Minor faulting has continued through the late Pleistocene and Recent.

ALGONKIAN AND EP-ALGONKIAN FAULTS OF THE BRIGHT ANGEL QUADRANGLE, ARIZONA

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Prominent northeast- and northwest-striking fractures produced in the Archean rocks in late Archean time localized block faulting subsequent to Unkar time. Diabase dikes of Chuar age were intruded in some post-Dox fault zones. A branch of the northeast-striking α Bright Angel fault was injected, as was a branch of the northwest-striking Ottoman fault. Diabase was intruded along the Hindu fault on Crystal Creek in the Hindu amphitheater. The Phantom fault was once continuous with the Cremation fault. These faults were offset by Ep-Algonkian displacement on the α Bright Angel fault. Post-Chuar faulting is best shown in the Vishnu quadrangle to the east. Monoclinal deformation of Paleozoic strata along the Hindu and the Phantom-Cremation faults was caused by reversal of the mid-Algonkian and Ep-Algonkian direction of displacement presumably during Laramide time.

DEFORMED STREAM TERRACES OF THE EEL AND VAN DUZEN RIVERS, HUMBOLDT COUNTY, CALIFORNIA

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The villages of Rohnerville and Hydesville are on the major terrace of a north-sloping flight cut on beds of the Wildcat Group (Miocene-lower Pleistocene) during successive late Pleistocene and

Recent accelerations of regional uplift by the Eel River and its tributary, the Van Duzen. Lower terraces are inclined 10′ to 2° northeasterly, while upper terraces have northeast slope of up to 3°. Progressive tilting is attributed to deformation on the north flank of a west-striking anticlinal axis concurrent with the regional uplift. Terraces north of the Rohnerville-Hydesville flight have south slope perhaps due in part to initial slope, in part to deformation. One terrace south of the flight, tentatively correlated with the major terrace of the flight, appears to have south slope attributable to rotation. The deformed terraces afford another evidence of northern California Coast Range orogeny continued from Pleistocene into Recent.

METAMORPHOSED PALEOZOIC SECTION IN THE CENTRAL MOHAVE DESERT, CALIFORNIA

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Thermally metamorphosed sedimentary and volcanic rocks, at least in part Paleozoic, occur as roof pendants in plutonic igneous rocks of probable Mesozoic age in the south half of the Lane Mountain quadrangle, Mohave Desert, California.

More than 25,000 feet of conformable strata crops out on the northeast side of the Calico Mountains. Unknown thicknesses above and below the exposed section are missing because of Mesozoic intrusions. Faults, intrusive bodies, and alluvial cover prevent complete understanding of the stratigraphy, but a partial columnar section has been established.

Metamorphosed clastic sediments predominate, the characteristic rock types being thin-bedded feldspathic quartzite, plagioclase-quartz-mica schist, thin-bedded fine-grained diopside-quartz-plagioclase hornfels, and recrystallized chert conglomerate. Marble and calc-silicate hornfels constitute less than 20 per cent of the stratigraphic thickness. Other notable rock types are metamorphosed volcanic rocks, now biotite-andesine amphibolite, meta-andesite, and amygdaloidal metabasalt. Poorly preserved circular crinoid stems in marble suggest a late Paleozoic age for at least part of these strata.

Not represented in the preceding section are several thousand feet of calc-silicate hornfels, schistose feldspathic quartzite, metamorphosed chert conglomerate, limestone conglomerate, and marble, which occur in intimately intruded pendants about 7 miles northwest of the Calico Mountains. Poorly preserved heavy-shelled, ribbed brachiopods in calc-silicate hornfels provide no more than a suggestion of a probable Paleozoic age.

The possible paleogeographic significance of this hitherto unknown Paleozoic clastic facies is discussed, and possible correlations are pointed out.

SYN- AND POST-OROGENIC GRANITIC EVOLUTION IN NORTHERN CASCADES OF WASHINGTON

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Sediments mainly of argillaceous character and volcanics predominantly of andesitic composition, mostly Upper Paleozoic, have during later Mesozoic intense orogeny become phyllites, green schists, greenstones, biotite schists, and amphibolites. In a central belt, synkinematic granitization has transformed schists and amphibolites into porphyroblastic and banded gneisses, and finally into varied granodioritic flasergneisses, interlayered with relict isochemical metamorphics. Regional metamorphism exceeds low grade only near and within the granitized belt. At the northeastern border of this belt, intensely folded Lower Cretaceous clastics have been dynamically metamorphosed into epizonal rocks, grading westward into underlying medium-grade rocks.

Within the gneisses, post-orogenic static recrystallization has produced directionless crystalloblastic granodioritic rocks in small bodies, patches, and structurally controlled replacement dikes including pegmatites. Structurally controlled mobilization has caused small-scale intrusion of crystalline migmatitic material, combining cataclastic with plastic features, sometimes succeeded by further feldspathization.

The western portion of the gneiss belt has been statically recrystallized into directionless granodioritic rocks on a large scale, under preservation of relicts, and without displacement of the gneiss, the

trends and folds of which remain undisturbed by nongneissose granodioritic areas. The southwestern marginal part of the granodioritic body has been mobilized. Plastic migmatitic material, generally still crystalloblastic, has moved from its genetic environment and become partly detached in stocks, shouldering aside nongranitized mostly epizonal metamorphics. Reaction between intrusive migmatite and wall rock has formed secondary contact migmatites.

On the east, post-orogenic feldspathization has somewhat advanced beyond the gneiss border. Farther east, the youngest granitic rock forms a pluton with igneous textures and hornfels contacts. It has shouldered aside nonmetamorphic and metamorphic Cretaceous and older rocks. This body is considered the product of liquification during the final stage of granitic evolution, and has migrated farthest from its source in the central granite-making zone. Porphyritic dikes connected with this intrusion are widespread.

INDICATOR MINERALS, COEUR D'ALENE SILVER BELT

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Ore shoots, rich in argential tetrahedrite, occur in quartz-carbonate veins in this area. The replacement veins are in the thick (up to 26,000 feet) Algonkian Belt series which is complexly folded and faulted.

A search is made for indicator minerals—*i.e.*, minerals whose spatial distribution may indicate the position of ore. In this respect, the spatial-distribution patterns of most of the vein and country-rock minerals are discussed, and the genesis and time relationships of the minerals are interpreted as an aid in the evaluation of these patterns.

Arsenopyrite is believed to be an indicator, apparently forming envelopes around ore shoots. Similarly, late hydrothermal chlorite is considered to be an indicator.

Sericite and carbonates of pre-hydrothermal-vein origin have a negative significance as indicators —*i.e.*, little ore has been found where these minerals are concentrated. Since beds rich in detrital quartz are the best ore horizons, such quartz is considered an indicator of limited practicability.

Regionally, the two most abundant constituents of the entire Beltian section are quartz and sericite. The widespread bleaching in Silver Belt has been called sericitization. Actually, the phenomenon appears only to involve destruction of the rock pigments (largely hematite and carbonaceous matter) and pyritization. If any sericitization be involved in the bleaching, it is negligible relative to that in the sediments long before the bleaching took place.

LITHOFACIES STUDY OF THE SALT WASH SANDSTONE MEMBER OF THE MORRISON FORMATION

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The Salt Wash sandstone, the lower member of the Upper Jurassic Morrison formation in a large part of the Colorado Plateau, is the product of an aggrading fluvial system and consists of lenticular beds of light-colored cross-laminated sandstone and conglomeratic sandstone irregularly interbedded with mudstone, claystone, and horizontally laminated sandstone.

The fluvial deposits are divided into stream and flood-plain deposits: the stream deposits include all sediments interpreted as deposited from moving water; the flood-plain deposits include all deposits interpreted as deposited from slack water.

The lithofacies of the Salt Wash member is the total aspect of the thickness, relative proportions, and continuity of the two types of deposits. Areal variations in Salt Wash lithofacies are shown by isopach and isolith maps.

Interpretations of the areal variations in Salt Wash lithofacies indicate piedmont-type deposition by a distributary drainage system from one principal source area. The distributary drainage radiated outward from south-central Utah and spread sediments to the north and east in a fan-shaped pattern. The total thickness of the deposits and relative proportion of stream deposits decrease rather uniformly away from the apex of the fan. In the Four-Corners area, where the Salt Wash member interfingers with the Bluff sandstone member of the Morrison, the development of the fan shape was interrupted as the distributary streams encroached on the sand dunes of the Bluff sandstone member.

NASONITE FROM CRESTMORE, CALIFORNIA

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Two minerals of the nasonite group, one bright yellow, the other pale bluish green, have been found in thin veins in an aggregate of finely sugary white garnet, wollastonite, and diopside, with occasional patches of blue calcite, in the 910-foot level of the Commercial Quarry, Crestmore, California. Both varieties show occasional crystals, as minute hexagonal prism and base. Slight differences in accessory elements seem to account for the variation in color. The nasonite is derived from earlier galena, which occurs sparingly in this area, usually in the blue calcite.

At least two other lead-bearing silicate minerals have been observed accompanying the nasonite, but are so far unidentified.

MAJOR SHEAR ZONE AT FALSE CAPE, HUMBOLDT CO., CALIFORNIA

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A westerly-striking, 3-mile-wide zone of heterogeneous rocks is exposed in the sea cliffs at False Cape. Only a few sandstone lenses outcrop as knobs in the upland areas, but occasional fresh cuts show that the zone extends at least 15 miles to the east. Where well exposed, the zone is composed typically of slickensided phacoids of hard, gray-green sandstone (predominant), red chert, gray limestone, and greenstone set in a matrix of finely divided, pelitic "gouge" (resembling the "crush-conglomerates" or "friction-breccia" of Lamplugh and Harker). Some of the lenses show a rude alignment through contorted folds indicating strong deformation, stretching of the sandstone beds, shearing into separate lensoid masses along minor slip planes, and plastic flow of the soft pelitic material (originally interbedded clay shales). Major faulting has caused considerable displacement in parts of the zone. Thin sections of the sandstone lenses show little, if any, internal deformation. Lithologic and meager fossil evidence indicates the zone contains rocks of Jurassic, Cretaceous and Pliocene age in an indiscriminate jumble.

Another similar zone strikes northwesterly about 10 miles south in the Mattole River area. It is suggested that these zones may be genetically related to the San Andreas Rift system and to an important, intersecting, westerly-trending, unnamed rift system. The offshore presence of this unnamed zone has been indicated by the distribution of epicenters of recent earthquakes and possibly by the Mendocino Escarpment and a recently described, seaward extension of a related, major topographic anomaly.

GENESIS OF THE RARE-EARTH DEPOSITS NEAR MOUNTAIN PASS, SAN BERNARDINO CO., CALIFORNIA

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Since the discovery of bastnaesite (a rare-earth fluocarbonate) in April 1949 in San Bernardino County, Calif., numerous deposits containing rare-earth minerals have been studied during detailed field mapping in a northwest-trending belt, about 6 miles long and 1½ miles wide, that crosses U. S. Highway 91 about 2 miles east of Mountain Pass. This belt is defined by the areal distribution of carbonate-rich rocks and of potash-rich intrusive rocks which, in order of intrusion into the pre-Cambrian metamorphic rocks, are: coarse-grained shonkinite, syenite, granite, and fine-grained shonkinite dikes. These carbonate-rich and potash-rich rocks are undated but are themselves cut by andesitic dike rocks of Mesozoic or later age.

The minerals in the carbonate-rich rocks include barite, calcite and related carbonates, bastnaesite, parisite, monazite, quartz, fluorite, sulfide minerals, apatite, allanite, magnetite, crocidolite, biotite and phlogopite, and a few unidentified minerals. The carbonate rocks occur in veinlike bodies up to 600 feet long and 20 feet wide and in irregular bodies. The largest irregular body, the Sulfide Queen, is about 2,400 feet long, is 700 feet in maximum width, and has an area of about 20 acres.

Extensive sampling by the U. S. Geological Survey indicates an average rare-earth oxide content between 5 and 10 per cent, with a range from less than 1 per cent to nearly 50 per cent.

The rare-earth-bearing carbonate rock is believed to be genetically related to the potash-rich intrusive rocks, but the nature of the fluids that transported the rare earths is unknown. The principal episodes in the history of the discovery, exploration, and development in this district are summarized.

VIRGIN FORMATION, ST. GEORGE AREA, SOUTHWESTERN UTAH

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Detailed stratigraphic studies of the Virgin limestone member of the Moenkopi formation in the St. George area, southwestern Utah, led to the elevation of this member to the rank of formation. Consequently, the Moenkopi formation has been elevated to the rank of group.

The Virgin formation is represented by near-shore marine and lagoonal facies. The sediments of lagoonal facies were deposited under a restricted arid environment.

Recent discovery of ammonite fragments identified by Professor Muller of Stanford University as *Tirolites spinosus*, *?Cordillerites*, and possibly *?Hungarites*, indicate the correlation of the Virgin formation with the uppermost part of the Lower Triassic.

FUSSELMAN LIMESTONE OF THE SACRAMENTO MOUNTAINS, NEW MEXICO

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In the Sacramento Mountains and other ranges farther west in south-central New Mexico, Darton identified the Upper Ordovician Montoya limestone, as well as two members of the Fusselman limestone for which a Middle Silurian (Niagaran) age has been generally accepted. Recent field work indicates that the major erosional break within the Montoya-Fusselman sequence occurs between the two members of the Fusselman limestone in the Sacramento Mountains. Fossils from the lower member appear to be Upper Ordovician, and those of the upper member appear to be Lower Silurian.

The lower member of the Fusselman limestone is lithologically distinctive, widespread, and easily mappable in south-central New Mexico. In the Sacramento Mountains it consists of 150 to 225 feet of medium to very light gray, sublithographic dolomite that contains little chert. No persistent erosional break has been observed at the base, but the upper contact is interpreted as a disconformity.

The upper member of the Fusselman limestone of the Sacramento Mountains consists of resistant, gray to brown, cherty dolomite up to 100 feet thick. The fauna includes *Pentamerus parvulus*, *Dalmanella edgewoodensis*, *Camarotoechia* ? cf. *C. festinata*, and *Loxoplocus fasciata*, similar to forms described by Savage from the Edgewood limestone of Missouri. Diagnostic Middle Silurian fossils have not been recognized, although known from the upper part of the type section of the Fusselman limestone.

Lower Silurian strata have been considered absent from southern New Mexico and West Texas. It appears probable that the lower part of the Fusselman limestone is of pre-Niagaran age elsewhere in this region.

PROPOSED GEOLOGIC MAP OF MONTANA*

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In 1944 a preliminary geologic map of Montana, without colors or patterns, was issued by the U. S. Geological Survey in co-operation with the Montana Bureau of Mines and Geology. This map filled a pressing need, and aroused so much interest as to emphasize the desirability of a more adequate, colored map. To this end, field work was carried on from 1946 through 1951, and the aid of

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numerous geologists of the Federal and State surveys and other organizations was enlisted. Compilation of the map is now complete; drafting, preparatory to transmittal for publication, is expected to be complete in the spring of 1952.

The map is to show 76 units. Most units for the pre-Cretaceous rocks are of systemic rather than formational rank. In mapping the boundary between the Mesozoic and Tertiary, long a problem, the work of Roland W. Brown has been accepted as the controlling guide. As the map primarily depicts the bedrock, the widespread mantle of Pleistocene deposits in the plains is not shown, although its southern limit is indicated.

Montana has marked contrasts in geology and topography, and is underlain by strata ranging from Precambrian to Recent, cut by intrusions of several kinds and ages. At least three major volcanic units are present; these and their structural relations are briefly described. Several new points have been brought out by the mapping done in connection with the compilation.

FLOW UNITS IN THE COLUMBIA BASALT AT THE DALLES DAM, COLUMBIA RIVER, WASHINGTON AND OREGON

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Upper strata of the Columbia basalt at The Dalles dam are exposed in channeled scabland and along terraced valley walls. Thick flows exposed up dip have been penetrated in drill holes beneath the site. Several flows are made up of tabular flow units. A study of megascopic properties reveals differences between flows and similarities between the flow units of a single flow. The flow units are 2–40 feet thick and a few hundred feet to more than a mile long. They are usually at the base of a flow and are miniatures of the parent flow, exhibiting the same types of vesicles, phenocrysts, and chilled zones.

GEOLOGY OF THE QUESTA MOLYBDENUM MINE, NEW MEXICO

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The Questa Molybdenum Mine, on Red River, north-central New Mexico, is unique in containing high-grade molybdenite ore in large fissure veins while most other production is from disseminated low-grade deposits. Operations began in 1916, and the mine has been in almost continuous production since then. Mining is by open and cut-and-fill stoping; concentration is by flotation. The ore contains from 1 to 5 per cent molybdenite. During the year ending June 30, 1951, production amounted to 83 tons of 90 per cent molybdenite concentrates, worth $92,994.

The ore occurs in an albite-rich granite stock along its east-west striking, south-dipping contact with greenstone. The veins range from less than an inch to 7 feet in thickness and are largely quartz and molybdenite, with fluorite, pyrite, chalcopyrite, and biotite locally abundant, and galena, sphalerite, and rhodochrosite present in smaller amounts. The apparent order of deposition was: (1) quartz; (2) quartz, molybdenite, and biotite; (3) pyrite, chalcopyrite, galena, and sphalerite; (4) fluorite; (5) rhodochrosite; and (6) later small amounts of molybdenite. The veins were filled by hydrothermal solutions which came in soon after the granite was intruded during middle Tertiary.

Two sets of fractures, one parallel to the granite contact and the other a regional east-west striking, north-dipping set, control the form and location of the ore body. On the south side of the stock, where the two sets of fractures have parallel strikes and opposing dips, they opened up, and the ore-forming solutions deposited the minerals as cavity filling with little replacement of wall rock.

DEBRIS FLOW OF 1941 AT WRIGHTWOOD, SOUTHERN CALIFORNIA

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On May 12, 1941, and for several days thereafter, the southern California resort community of Wrightwood on the north side of the San Gabriel Mountains was partly inundated by a series of debris waves. The immediate cause of debris flowage was rapid melting of deep winter snow by a week of

exceptionally warm weather. Intense shattering of the bedrock (Pelona schist) within the San Andreas rift zone at this location also contributed materially to preparing debris for flowage.

Study of the flow deposits and eyewitness accounts provide the following information. Debris was transported 15 miles by mass movement, and on a gradient as low as 75 feet per mile at the outer extremity. The flow advanced in successive waves of slimy gray "cement-like" mud containing abundant stones. Velocities of most waves did not exceed 3–5 miles per hour (estimated). The front of an advancing wave was a steep bouldery embankment a few to 15 feet high shoved along by the more fluid material behind. Density of the fluid debris was 2.4, indicating a water content of 20-25 per cent by weight. Its viscosity is calculated at approximately 5×10^3 poises. Mechanical analyses give an average sorting coefficient of 3.94. Cumulative curves also demonstrate a poor degree of sorting but somewhat better than in many glacial tills which the flow debris strongly resembles. Debris flows have previously occurred here; others will undoubtedly take place in the future.

LOCALIZATION OF ARIZONA CHRYSOTILE ASBESTOS DEPOSITS

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Chrysotile asbestos deposits of east-central Arizona are genetically related to the intrusion of small dikes and extensive sills of diabase into late Precambrian Mescal limestone. Chrysotile occurs as cross-fiber veins that approximately parallel the bedding of the limestone. The host for the veins is serpentine which differentially replaced certain limestone beds.

The localization of the asbestos deposits was influenced by bedding-plane and thrust faults, folds, favorable limestone beds, and proximity of diabase to these beds.

Small-scale bedding-plane faults and thrust faults, probably the result of adjustment in the limestone when the diabase was intruded, constituted the most significant factor in determining the extent of the asbestos deposits. Small open folds, resulting from diabase intrusion, influenced the distribution of zones of fracturing related to bedding-plane faulting; the largest asbestos deposits are associated with such folds.

A few of the more massive, more competent beds of the lower member of the Mescal limestone were the most susceptible to fracturing and therefore to mineralization; recognition of this stratigraphic control is important in evaluation of individual deposits.

Proximity of diabase to favorable limestone beds is essential; only rarely do mineable asbestos deposits exist more than a few tens of feet stratigraphically above or below a diabase sill. Where locally a sill cuts discordantly across a favorable bed, asbestos-bearing serpentine zones may extend along the bed for several tens of feet or, exceptionally, a few hundreds of feet from the limestone-diabase contact.

A study of vein structures suggests that cross-fiber veins can best be explained as fillings in tension fractures that were gradually or recurrently opened.

ARE THE PETALUMA HORSE TEETH RELIABLE IN CORRELATION?

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When the Petaluma horse, *Neohipparion gidleyi* Merriam, was described in 1915 our knowledge of the sequence of equinae species had not progressed far enough to permit age or stage refinement in correlation. We now recognize three genera among the hipparion-like horses that were supposedly indicative of a Lower Pliocene age in 1915. Furthermore we recognize certain phyletic lines in each of these genera and thus can correlate early or late divisions of the provincial ages now used by vertebrate paleontologists.

There are two distinct species groups listed under the genus *Neohipparion*. The *occidentale* group is of Clarendonian age (early Pliocene) with the possibility of rare representation in the earliest Hemphillian (middle Pliocene). The *eurystyle* group is composed of Hemphillian species. *N. gidleyi* is clearly referable to the second group, and its characters show that it is one of the most advanced species in the group.

Some of the most recent papers on the geology of the San Francisco Bay region (Morris and Bailey,

1935; Weaver, 1949; Taliaferro, 1951) have not utilized the evidence from the fossil vertebrates in the Petaluma formation but have continued to correlate the Petaluma with the Siesta or the Orinda (Clarendonian) of the Berkeley Hills. It should be recalled that no species of *Neohipparion* has been found in the Siesta and Orinda or their equivalents north of the Tehachapi and west of the Sierra Nevada Mountains. If *N. gidleyi* is not a later Hemphillian (middle Pliocene) (Stirton, 1939; 1939; 1951), then our concepts of the evolution in later Cenozoic Equidae are erroneous.

PALEOGEOGRAPHY OF NONMARINE LOWER CRETACEOUS IN THE ROCKY MOUNTAINS

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Lower Cretaceous sediments indicate unusually uniform continental conditions over an area embracing most of the territory between the present Great Basin and the Mississippi River. Basal units, regardless of names applied, are usually conglomeratic with pebbles composed of durable rounded cherts and quartzites. Derived fossils indicate a source in late Paleozoic and perhaps Triassic formations to the west.

Above the conglomeratic beds is a thin sequence of variegated shale marked by numerous limy nodules, scattered "gastroliths", and pronounced lavender tints. Compared with the Morrison formation which is of similar origin, the Cretaceous nonmarine beds are very scantily fossiliferous. Evidence seems to indicate a semiarid environment over a wide area.

STRATIGRAPHIC PALEONTOLOGY OF THE TYPE SECTION OF THE TOPANGA FORMATION, SANTA MONICA MOUNTAINS, CALIFORNIA

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The Middle Miocene Topanga formation at its type locality in Topanga Canyon, 10 miles northwest of Santa Monica, Los Angeles County, California, consists of more than 8000 feet of conglomerates, sandstones, and shales with intercalated basalts. The formation here disconformably overlies the Oligocene Sespe formation and underlies the Upper Miocene Modelo shales with marked angular unconformity. An abundant molluscan fauna, obtained from four horizons within the formation, is divisible into two major faunal assemblages separated stratigraphically by 1200 feet of barren beds. The lower assemblage ranges through about 200 feet of strata at the base of the formation and is characterized by the presence of *Turritella ocoyana* s.s. and *Pecten* (*Lyropecten*) *crassicardo*, n. var. The upper assemblage ranges through the three upper horizons and is characterized by the presence of numerous specimens of *Turritella ocoyana topangaensis* and *Turritella temblorensis*.

BEDROCK COMPLEX OF THE SIERRA NEVADA IN THE VICINITY OF SONORA, CALIFORNIA

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An area of low-grade dynamometamorphic rocks has been mapped in the vicinity of Sonora, California. The rocks, probably pre-Cretaceous, belong to the bedrock complex of the Sierra Nevada. This complex is divided into two groups: the low-grade dynamometamorphic rocks and younger, relatively unaltered granitic rocks that make up the batholithic core of the Sierra Nevada. Rocks of the latter group are not exposed in the mapped area.

The pre-granitic rocks were originally volcanic materials interlayered with a lesser amount of sedimentary rocks and cut by stocks and dikes of mafic composition. These volcanic, sedimentary, and mafic intrusive rocks were subsequently altered to low-grade metamorphic rocks of the chlorite zone. These rocks belong to two subzones, which have been brought into juxtaposition along a fault of the Mother Lode belt. The rocks on the east side of the fault are mineralogically reconstituted and are of higher grade than those on the west, which retain many of their original characteristics.

The homogeneity of the volcanic rocks, the lack of fossils, and the metamorphic alteration make correlation difficult; the stratigraphy of the area is not yet clearly understood.

RING DIKES OF THE CONTINENTAL DIVIDE REGION, PANAMA CANAL ZONE

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Detailed geological studies for the Third Locks Project between 1939 and 1945 and subsequent investigations made toward selection of location and type for a new, improved canal have disclosed the presence of basaltic ring dikes that outline the base of many Canal Zone hills. Location and distribution of these dikes are directly related to the geomorphic history of the region. Most of the hills are composed of hard igneous or pyroclastic rocks which rest on weak sedimentary strata. Tertiary faulting on steep planes which curve around or are tangential to the base of the hills has inset the harder rocks into the sedimentary series. Later, these lines of weakness were invaded by basaltic magmas. In a few cases, core borings have indicated that the basalt completely encloses the buried bases of the hills so that these dikes can be more aptly described as "cup dikes" rather than ring dikes.

WEATHERING AND STRUCTURAL FEATURES AT FOLSOM DAM, CALIFORNIA*

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Folsom Dam, about 25 miles northeast of Sacramento on the American River, currently is under construction by the Corps of Engineers. Generally satisfactory granodiorite foundation rock is exposed on both abutments of the concrete gravity dam. The character of the foundation is controlled by the effects of weathering, by a minor but complicated system of faults, and by closely spaced joints, many of which show the effects of hydrothermal action. Petrographic work on a limited number of specimens from local areas suggests that weathering is principally the result of mechanical rather than chemical action. Mineral grains are micro-brecciated, feldspars internally are unaltered although clouded along the fractures, while biotite and accessory hornblende are fresh. The degree of weathering varies in all directions, and it may be that micro-brecciation may account for fresh rock grading into thoroughly disintegrated rock within short distances. Further study is needed to check these limited observations. A prominent and controlling joint set strikes N. 45° E., dips 45° NW., with another at N. 30° E., dipping 32° NW.; a third strikes N. 88° E., dips 78° SE., with a fourth at S. 75° E., dipping 84° SW. Many of these joints show displacement of 6 inches to 50 feet with accompanying clay gouge and occasional hydrothermal alteration of the wall rock. The diversion tunnel is opening rock at greater depth than on the abutments and shows a more widespread and diverse pattern of joints and faults than anticipated.

TRANSPARENT PACKING MODELS OF COMPLEX SILICATE MINERALS

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Models illustrating the atomic arrangements of minerals in which the atoms are represented by spheres or deformed spheres with radii proportional to the radii of the ions (or atoms) in the crystals are a valuable aid in the visualization of the structures, and have the advantage (in respect to models in which only the positions of the centers of the ions (or atoms) are represented) that the co-ordination of each ion (or atom) is easily perceived. With models of the packing type made up of opaque spheres, groups of ions (or atoms) in the interior of a complex structure are, however, in many cases hidden from view. Models of this type in which all the ions (or atoms) except the very small ones are represented by skeleton spheres formed by celluloid-strip great circles (such models were first constructed by Mr. John Rannells) are free from this disadvantage. Ions of different elements are made of celluloid of different colors in addition to their having, in most cases, different sizes.

A model of this kind of the structure of muscovite serves as an illustration.

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GROUND WATER IN THE QUEEN CREEK AREA, ARIZONA

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Queen Creek flows westward into the structural basin known as the Salt River Valley area. Within 25 miles the following features of the hydrologic cycle, as applicable to southern Arizona, are present: Rainfall in the upland areas causes runoff, which recharges the ground-water reservoir beneath the lowlands; the water moves to the area of discharge; pumping lifts the water to the surface where it returns to the atmosphere by transpiration and evaporation; locally native vegetation transpires ground water without benefit to man.

Alluvial fill in the area consists of boulders, gravel, sand, silt, and clay. The materials are coarse-grained near the mountains and become progressively finer-grained downstream. Caliche under the desert surface retards or prevents recharge except along stream channels.

Ground water has been pumped for irrigation since at least 1915. Postwar high crop prices caused thousands of acres of new lands to be farmed. Pumpage in 1938 was 101,400 acre-feet, and in 1950, 295,000 acre-feet. Recharge from Queen Creek between February 12, 1940, and March 18, 1941, a wet period, was about 32,000 acre-feet.

The pumping in excess of annual recharge has caused a decline of the water table. In the cultivated area, the decline during the period 1939–1951 has ranged from 25 feet on the east side to 53 feet on the west side. Specific yield and permeability of the alluvium decrease with depth, so that, for each succeeding foot of lowering of the water table, less water is yielded, and the drawdown in wells at a given yield is greater.

RELATIONS OF IGNEOUS AND METAMORPHIC ROCKS TO OROGENY

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Orogeny, regional metamorphism, and igneous activity are broadly associated in time and space. None of the three is the direct cause of the other two processes, but all are regarded as crustal manifestations of thermal adjustments occurring in the underlying mantle. Igneous activity associated with orogeny involves independent development of at least two magmas, one "basaltic" and the other "granitic."

The following propositions are offered for discussion. (1) Spacing of isograds in regionally metamorphosed areas indicates a rate of heat flow at the time of metamorphism several times the present one; (2) heat requirements for metamorphism and formation of magma probably exceed the mechanical energy of deformation and uplift; (3) this suggests, as Kennedy has pointed out, that orogeny is essentially a thermal phenomenon, the intensity of deformation being dependent on the temperature distribution; (4) the main factor in heat transfer and metamorphism is probably juvenile water released by partial fusion, resulting from a convective overturn, of the meteoritic matter forming the underlying mantle.

CONTACT METAMORPHISM ALONG ALGONKIAN DIABASE SILLS, DEATH VALLEY REGION, CALIFORNIA

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Well-developed zones of silication border diabase sills of the Algonkian Crystal Spring formation, an extensively exposed unit in the southern Death Valley region. The zones, alterations of strata in a massive carbonate member near the center of the formation, are as much as 150 feet thick and persist along most of the contacts between diabase and carbonate rock. The original rock was generally a siliceous to silica-poor dolomite.

The most common alteration minerals are hydrous magnesium silicates (talc, tremolite, and serpentine); other abundant but less-widespread minerals include alkali feldspar, silica, diopside, and sericite (?). The lowest major sill, which everywhere lies near the base of the carbonate member,

ordinarily is bordered by zones of white talc-tremolite-serpentine rock of commercial interest. A green tremolitic rock, generally with abundant feldspar, occurs in altered septa within the sills, and in zones adjacent to sills higher in the member. Many of the alteration bodies at the base of the member are composed of layers of contrasting lithology, each 5 or more feet thick. A typical layered sequence outward from a diabase contact consists of (1) thinly laminated tremolitic rock, (2) talc schist, and (3) crudely laminated rock rich in silica, feldspar, and sericite (?) as well as talc, tremolite, and serpentine.

MgO and SiO_2 have been introduced to form the highly talcose or tremolitic rock; SiO_2, Al_2O_3, K_2O, and probably Na_2O to form the feldspathic rock. Diabase magma was probably the source of most of the additive material, but some may have been derived from connate water.

DYNAMIC TEST OF A FOUR-STORY, REINFORCED-CONCRETE BUILDING

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In order to investigate dynamic properties which govern the response of structures to earthquakes, forced vibration tests were conducted on a four-story, reinforced-concrete building. Deflections and accelerations were produced which approached the magnitude of those experienced during strong-motion earthquakes. Damping values were calculated from the resonance curves obtained. The results show that the total damping in the structure is small and that the damping apparently increases with increasing amplitude of motion. Within the accuracy of the measurements, the damping was independent of the frequency of the motion. Results of previous studies indicate that the damping observed in this investigation is sufficient to cause significant reductions in earthquake stresses.

PROGRESS REPORT ON CAPACITY-TRANSDUCER SEISMOGRAPH

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Development has continued on capacity-transducer seismographs described at the two previous meetings of the society. A horizontal-component pendulum seismometer has been completed. In addition to galvanometer recorders, the vertical instrument is now operating a magnetic tape recorder and an ink recorder. Provision is also made for operation of a Sanborn hot stylus recorder. The visible writers and the tape recorder operate simultaneously from a single two-stage push-pull amplifier coupled to the diode output of the seismometer. Alternating current bias for the recording head is taken from the 60 cycle/sec power line. The recording speed of the magnetic tape is 0.5 or 0.25 mm/sec. For playback the tape is speeded up to 15 inches per second corresponding to an acceleration of 750 or 1500.

RECENT ACTIVITY OF THE INDIAN OCEAN SEQUENCE

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The sequence of shallow earthquakes which began April 11, 1925, in the Indian Ocean near latitude 34° S., longitude 58° E., exhibited an elastic strain-rebound characteristic which up to October 24, 1933, was accurately represented by an equation of the form $S = a + b \log t$. Following the shock of that date the fault was locked strongly, so that no further earthquakes were produced for some 16 years. During this quiescent interval, if strain were accumulating in accordance with the above equation, it was possible for any given date to predict the magnitude of the earthquake required to reduce the accumulated elastic strain of the fault to zero. Thus in 1949 the accumulated strain was sufficient to generate a 7.5 magnitude earthquake. On October 7, 1949, the sequence became active again with the production of a magnitude 6¾ shock. This shock relieved only a small fraction of the strain. However, on December 8, 1951, a magnitude 7.5 shock occurred which relieved all the accumulated strain to within 0.1 magnitude of the value predicted by the equation. The equation $S = a + b \log t$ represents an elastic (or recoverable) creep which may be either an elastic afterworking following an earlier creep strain accumulation or a forward creep in response to an external force. If the former case is the correct one, this sequence will die out. If the latter case obtains, then large elastic and creep strains are stored in the fault blocks outside of the sequence earthquake-generating zone. If these blocks should fracture, a great earthquake of magnitude 8 or larger could be generated.

AMPLITUDES OF P_n WAVES FROM 3° TO 23°

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Thirteen earthquakes on the west coast of the United States and Canada were investigated using records from stations along this coast from Seattle to La Jolla. The amplitudes of the ground motion due to P_n were reduced to a period of 1 second and a uniform magnitude by Gutenberg's method. The position of the stations and of the epicenters precludes any important variations in amplitudes due to azimuth. A diagram of amplitudes versus distance shows no minimum; the law suggested is a continuous decrease with the distance, but the scattering is large.

T PHASES FROM HAWAIIAN EARTHQUAKES

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Eleven earthquakes, eight centering under Hawaii and three under adjacent seas, have written good T phases at the San Francisco Bay stations. Four have recorded well at Mineral, and two at Shasta. They indicate water speeds from 1.46 to 1.55 kilometers per second. The 1.55 speed was recorded on only one large shock (January 23, 1938). A later arrival on these seismograms indicated a water speed of 1.47. This large shock centered at sea. The Coast Survey gave it a 60-kilometer depth of focus. In further observations we exclude the early arrival for this shock.

Plotting Berkeley arrivals of T against epicentral distance, we find a velocity of about 3.7 $\frac{\text{km.}}{\text{sec.}}$ which we attribute to land path in Hawaii.

Plotting first arrival times at various stations minus the arrival time at Berkeley against epicentral distances minus that at Berkeley, we find a speed of about 7 kilometers per second which we attribute to land path in California.

The periods of recorded T waves run from 0.25 second to 0.7 second. The period variation does not appear to be the result of dispersion.

LOCAL, NEAR-REGIONAL, AND REGIONAL EARTHQUAKES

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A classification according to distance, based upon the physical character of records of shallow earthquakes having continental foci, is suggested as follows: (1) *Local Earthquakes* 0 to about 150 km. The first arrival is the relatively strong $\overline{P}$ wave which follows the most direct path from focus to station. The dominant wave period is usually from 0.1 to 0.2 sec. (2) *Near-Regional Earthquakes*, 150 to about 650 km. The first arrival is the relatively weak but distinct P_n which penetrates the mantle where the speed is greater; the more energetic $\overline{P}$ wave arrives later. The short-period waves become less dominant with distance. (3) *Regional Earthquakes* 650 to about 1600 km. These earthquakes lie in the regional shadow zone of Gutenberg. The quantity P_n is relatively very weak and is often difficult to separate from the background; $\overline{P}$ disappears as distance increases; S_n and $\overline{S}$ are distinguished with difficulty; and surface waves dominate the record. Wave periods are rarely less than 0.5 sec. (4) *Teleseisms*, 1600 to 20,000 km. The quantity P_n is again relatively strong. If the focus is in the mantle, the first arrival is relatively strong regardless of distance.

SEISMIC ACTIVITY IN WASHINGTON FROM 1865 TO THE PRESENT

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The State of Washington is one of the more active seismic areas in the United States. To gain some information regarding this activity the historical data were plotted in a variety of ways. Charts were prepared showing the time, frequency, and intensity of earthquakes from 1865 to the present.

The records prior to 1906 are from historical accounts, newspapers, and various seismological publications. Since 1906 the seismograms from the University of Washington have provided much of the necessary information. Maps have been prepared showing the distribution of the more severe tremors together with their relative intensities.

The new seismographs installed at the University of Washington in 1949 give considerable supplemental data to the macroseismic observations. In 1950 the Seattle station recorded 77 earthquakes with epicentral distances of 7 degrees or less (Vesanen and Jones, 1951).

The macroseismic studies show the following results: the intensity of local earthquakes has increased materially during the past decade; an average of one earthquake per year has been felt; and the greater number of earthqukaes occur in the southern end of the Puget Sound region.

COMPARISON OF MICROSEISMS AND OCEAN WAVES RECORDED IN SOUTHERN NEW ENGLAND

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Three cases of high ocean waves and simultaneous microseisms recorded respectively at Cape Cod, and Weston, Massachusetts, are given. The first case compares the high swell with the microseism storm associated with a passing marine hurricane. Time relations of microseism and swell amplitudes together with the comparison of periods strongly suggest that the microseism storm originated not from action of local swell or surf but from forces directly in the hurricane area.

The next two cases compare simultaneous wave and microseism records for intervals of much more pronounced local wave activity when maxima of 11- and 15.5-foot waves were recorded, and when no significant offshore storms existed. During these intervals new, but very feeble, short-period microseism trends with maximum amplitude increases of only 0.8 mm were noted, and these followed the wave rather than the wind changes. It is suggested that these weak microseisms are of true surf origin. Again the study negates surf or shallow-water swell as the generating force of prominent microseism storms commonly associated with marine cyclonic or strong cold frontal disturbances

STUDY AND EVALUATION OF THE TRIPARTITE SEISMIC METHOD OF HURRICANE LOCATION

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U. S. Navy tripartite records from several stations were studied for the five main Atlantic hurricanes of 1950. Azimuths were computed for both average and individual wave measurements. Although the errors in hurricane location of 20 to 60 degrees with modal values of 30 to 40 degrees indicate poor applicability for operational purposes, they nevertheless give encouragement for the establishment of storm positions with greater certainty by this method. Since these errors are much greater than the theoretical expected errors for these stations an investigation of the sources of error was made. These are considered as resulting from instrumentation and procedure and from anomalous travel times across the tripartite nets, this latter being mostly associated with significant period differences of "unique" waves recorded at each instrument.

A large number of velocities were computed for each station, and these showed a wide range around definite modal values. The velocity study suggests that microseisms may be the result of interference of waves traveling different paths as a consequence of refraction and broad or multiple-source areas. A number of suggestions for the improvement of the procedure are derived from the study.

BUILDING CODE REQUIREMENTS FOR EARTHQUAKE-RESISTANT DESIGN

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The inclusion of provisions for earthquake-resistant design in building codes has been difficult in the past. While the need is usually recognized, arguments over cost increases, and type and severity

of provision, make adoption difficult. The engineering profession is responsible for much of this confusion.

Cost increase is usually small, often negligible. The means whereby any structure can be made earthquake safe are well known, and of proven effectiveness in many past shocks. The argument often advanced by engineers that nothing should be done due to lack of knowledge has no basis of fact.

Confusion has resulted over arguments relative to a static or dynamic method of design. This argument is useless. The merits of a static type of design within certain limits have been proven beyond a question of a doubt in many past disasters. For certain types of structure a dynamic approach would be logical. The engineering profession, in the public interest, should stop this useless contention and should present a united front. In any code there is room for both a static and a dynamic approach.

DIRECTION OF APPROACH OF RAYLEIGH WAVES AND RELATED PROBLEMS

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A major problem in the study of Rayleigh Waves has been the apparent departure of observed surface-wave characteristics from the predictions of theory. The principal inconsistency has been the generally accepted conclusion that vibration of an earth particle is frequently in an orbit which departs from the plane of propagation of the wave motion. This conclusion is based upon the assumption that all wave motion has followed the direct epicenter-station path.

This assumption was tested in the investigation here reported by applying tripartite methods to surface-wave arrivals from distant earthquakes. The plane of propagation of the wave motion was so obtained. The plane of particle vibration was obtained by vectorial combination of the E-W and N-S components of motion. The records used were those obtained from the Wood-Anderson seismometers installed at San Francisco, Palo Alto, and Berkeley.

A comparison of these two sets of data indicates that the earth particle, during the passage of Rayleigh Waves, is moving in an orbit limited to the plane of propagation of the wave motion and that departures of this direction from the epicenter-station direction are due to variations in the direction of arrival of the waves. The assumption of great-circle propagation of all surface waves must therefore be abandoned. The departures from great-circle paths are of the type and in the direction predicted by a heterogeneous crust theory.

Phase velocity data indicate also the adequacy of isotropic-layer theory.

LOVE WAVE DISPERSION AND THE STRUCTURE OF THE PACIFIC BASIN

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An investigation of layering in the Pacific Basin is made by the use of Love Wave data obtained from records of the earthquake of 29 September 1946. The path from epicenter to Berkeley was mid-Pacific. The dispersion curve, when interpreted in the terms of two-layer theory, indicates the presence of

2.5 kilometers with V_s = 2.31 km/sec.,
11 kilometers with V_s = 3.87 km/sec.,
and bottom with V_s = 4.52 km/sec.

These values are compared with the refraction-shooting results of Raitt.

SHEAR-WAVE PROPAGATION AND CONTINENTAL STRUCTURE

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Data from rockbursts and from earthquakes of northeastern North America are used to investigate the phase Lg, Sn, and S. Previous results in which Lg is considered as a guided shear wave in the crustal layers are confirmed, and the phase is now well observed for distances of a few degrees out to 50°. The phases Sn and S are two separate branches of a shear wave travel-time curve, in agree-

ment with the earlier work of Lehmann and Gutenberg. Sn is recorded with periods of 1 sec. or less from 2° to 18°, and S appears with periods of 6 to 15 seconds from 11° to 33°. In the region from 11°to 18° the Sn and S branches overlap with Sn about 30 sec. earlier than S. These features of Lg, Sn, and S are explained by a single hypothesis involving transmission of shear waves through a structure consisting of a sialic layer bounded by the Mohorovicic discontinuity at about 40 km, a thinner simatic layer, a viscous liquid layer some tens of km thick, overlying a solid mantle in which the velocity of shear waves increases gradually with depth.

SEISMIC-REFRACTION MEASUREMENTS IN THE ATLANTIC OCEAN BASIN: PART IV, TYPICAL DEEP STATIONS, NORTH AMERICA BASIN

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Six reversed seismic-refraction stations 60 to 100 km in length were made in the North America Basin—three in the basin northwest of Bermuda and three in the basin south of Bermuda (Nares Deep). Five of these stations were carried out far enough to give a good determination of Pn; the sixth gives only a fair determination. These refraction stations form the best set of measurements to date on the seismic structure of the North America Basin and are believed to be typical of the basin of the western North Atlantic. An average velocity of 1.8 km/sec and average thickness of 1.2 km were determined for the sedimentary layer; a velocity of 6.4 km/sec and thickness of 4.4 km were found for an intermediate basement layer; and a velocity of 7.9 km/sec starting at a depth of 10.3 km below sea level was identified with Pn of continental seismology. The layer of unconsolidated sediment is about twice as thick in the basin northwest of Bermuda as in the Nares Deep, 1.56 km and 0.73 km respectively, and, since the depth to basement is nearly the same in the two regions, the greater thickness of sediments is expressed as a difference in the bathymetric level of the two basins (300 fathoms for the Nares Deep and 2600 fathoms for the basin northwest of Bermuda). The results of these stations are compared with earlier data and are shown to agree with Rayleigh Wave dispersion data.

MICROSEISMS WITH PERIODS OF 5–8 SECONDS IN THE PACIFIC COASTAL AREA, NOVEMBER 25 TO DECEMBER 6, 1951

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Original records of microseisms at Tacubaya, Tucson, Palomar, Pasadena, China Lake, Tinemaha, Santa Clara, Berkeley, and Seattle are studied. A high peak was reached at the southern stations on November 29, apparently in connection with a minor tropical disturbance near the top of Lower California. High peaks at the northern stations seem to be related to nontropical disturbances. The properties of the two types of microseisms, especially the differences in propagation, are discussed.

SURFACE MOTION IN SV AND SH

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The motion of the ground at the earth's surface produced by continuous sinusoidal transverse waves is discussed. If incident SV waves are totally reflected (angle of incidence greater than about 35°, epicentral distance roughly between 30 and 3000 km in shallow shocks) the ground particles should move in ellipses. This elliptic ground motion is not a surface wave in the proper sense, since it does not propagate energy along the surface and does not have a velocity of its own.

Characteristic examples of calculated ground motion are shown. Equations are given to find the amplitudes and polarization of the incident SV waves and the amplitudes of the SH components from the recorded S waves. Advantages of using records of Benioff strain seismographs to identify SV and SH waves are discussed. Characteristic S phases recorded by a variety of instruments at Pasadena are reproduced. No evidence is found for a suspected delay of SV relative to SH.

PROGRESS REPORT ON THE FAULT PLANE PROJECT

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The Dominion Observatory is carrying out a program to exploit as fully as possible Byerly's technique by which the direction of faulting in an earthquake is determined from the distribution of initial motion compressions and dilatations. As a first step, tables have been prepared permitting the method's application to earthquakes of any focal depth.

Solutions have been obtained for 20 earthquakes of various focal depths up to 600 kilometers. Two earthquakes in the Hindu-Kush appear due to normal faulting, but of 18 circum-Pacific earthquakes 11 are clearly transcurrent, and most of the others have large transverse components. This was true for the Peruvian earthquake of November 10, 1946, in which vertical displacements were observed in the field. The solution did substantiate the fault strike almost exactly, and the displacement discrepancy is believed due to the fact that first motion originated at a depth of about 20 kilometers and not at the surface.

If it could be established that transcurrent faulting predominates in Pacific earthquakes it would have a profound effect on tectonophysical thought. The earthquakes so far considered have been carefully selected and may not be typical. It appears desirable that an analysis should be attempted for all earthquakes of magnitude greater than 7, but this can be done only if machinery can be set up to supply data on first motions in a routine way. A strong plea is made that the Seismological Society of America should consider setting up this machinery.

CRUSTAL STRUCTURE AND SURFACE-WAVE DISPERSION. PART III: THEORETICAL DISPERSION CURVES FOR SUBOCEANIC RAYLEIGH WAVES

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Theoretical Rayleigh wave-dispersion curves for three types of suboceanic basement layering are presented. Previous conclusions concerning the dispersion of Rayleigh waves across ocean basins are re-examined in the light of the new data.

GRAVIMETRIC INVESTIGATIONS IN THE STATE OF WASHINGTON

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Although the presence of abnormal gravity anomalies in Western Washington has been known for many years, little attention has been given them until recently. During the past year the Geology Department of the University of Washington has sponsored a program of regional gravitative mapping of the State of Washington with station intervals of 5–10 miles. A Frost-type gravimeter, obtained for this work through the courtesy of a geophysical exploration firm, has given excellent performance and accuracy.

This paper presents a discussion of the large Free-Air anomalies and steep gravity gradients in the Puget Basin of Western Washington that have been mapped in the past year, their general relationships to the basin, and some implications as to its structure. Plans for continued gravimetric investigations in Washington and adjacent areas are also briefly outlined.

CARIBBEAN AND ATLANTIC T PHASES

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A further study shows that the T phase of Caribbean, Atlantic, and Central American shocks travels through the ocean with the velocity of sound in water. Bermuda seismograms show T phases for practically all reported Atlantic and Antillean shocks, with small scatter in velocities.

From May through November 1951 continuous records of the SOFAR Station at Bermuda have large trace amplitudes with predominant energies from 10 to 25 cycles per second when land instruments receive T phases with periods from 0.5 to 1 second.

Many of the small local shocks detected by the Benioff short-period vertical seismograph at San

Juan produce ample disturbances on the Bermuda SOFAR record, with travel times closely comparable to those of SOFAR bombs at similar distances, although the amplitudes on land are too small to be seen by Benioff seismographs.

A monogram is presented to simplify land-path corrections for travel time of the T phase, using the velocities 4.52 to 8.15 km/sec for the land path.

MISLEADING INFORMATION OBTAINED FROM THE PRESENT EARTHQUAKE INTENSITY SCALES

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The main purpose of any group or individual who studies earthquakes should be to protect the public life, health, and investment. The seismologist can best achieve these results by working with the engineer because the engineer designs the structures, appraises them for insurance, and prepares the codes under which they are constructed.

The engineer first wants to know the probability of an earthquake in the area in which he is designing a structure. Next, he wishes to know the maximum intensity of the earthquake that he could expect.

At present about all we know about earthquake probability and the possible intensity is by the past history of the area. This has been misleading because the methods used in rating the intensity have been based too much on human emotion and a disregard of construction methods.

In California where earthquakes are quite frequent the public has become less excited than they would be in another area, the buildings are better constructed because of the awareness of the potential danger, and the weak buildings have been destroyed or damaged by previous tremors.

The present intensity scales mean very little in the way of forces that would cause objects to move or fail. In every earthquake of destructive intensity the engineer is called upon to investigate structures. He should fill in standard forms, and an analysis should be made as to what force was necessary to cause motion before the earthquake is finally given its intensity rating.

MAGNIFICATION OF ELECTROMAGNETIC SEISMOGRAPHS SIMPLIFIED

Leonard M. Murphy

A mechanical sine-wave simulator instead of a shaking table is utilized for impressing sine-wave motions on the pendulum of a Spreng-nether horizontal seismometer by controlling through a potentiometer the voltages in two coils symmetrically placed about a small iron mass attached to the boom. When the simulator operates through a spectrum of periods the magnetic field of one coil passes through a maximum, while that for the second passes through a minimum. Simultaneous motions of the pendulum and galvanometer are recorded optically using various galvanometer periods and degrees of damping. In measuring the optical magnification of the pendulum a series of static pendulum displacements is measured with a micrometer. Ratios between pendulum and ground motions for various periods are determined from a standard magnification curve. For the period ranges there is a slight difference in the pendulum motion when swinging freely and connected in the galvanometer circuit. The responses of galvanometer to seismometer motions are measured, and the magnification curves are computed for the pendulum operating at a natural period of 5.7 seconds. Significant peak magnifications for different galvanometer periods are (a) with overdamped galvanometers: 23700 at .52 sec.; 3300 at 6.1 sec.; 1000 at 20.7 sec.; and (b) with critically damped galvanometer: 5100 at 1.97 sec.

SOME NEW CONCEPTS OF STRONG EARTHQUAKE MOTION

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A preliminary investigation of strong-motion accelerograph data, intensity distribution (MM Scale), and related information reveals the probability of early development of a reliable formula that will state, for any intensity of earthquake motion, the accelerations or amplitudes to expect for any ground periods that may be present in a destructive earthquake. Intensity of earthquake motion concerns not only destructive short-period waves but also those of longer period and lower acceleration that are related to them through a period-acceleration attenuation formula. A tentative table of such values is given. Consistent evaluations of the intensity of motion in basement rock are ob-

tained from three types of information: strong-motion seismograph data, teleseismic data (in the form of earthquake magnitudes), and descriptive information on intensity distribution obtained from questionnaire canvasses. Results indicate that maximum surface intensity occurs where a "strong point," or point of maximum resistance to fault slipping, finally gives way to accumulating stresses. Such point may or may not be identical with the instrumental epicenter, or with the point of maximum fault slipping.

Period-acceleration graphs reveal that in basement rocks the acceleration decreases exponentially on both sides of the maximum which occurs on the average close to a ⅓-second ground period. In the long-period portion of the spectrum, however, the exponential character of the decrease in acceleration is frequently masked by overburden effects. A larger attenuation rate observed in some shocks for the longer-period waves suggests earthquake foci in sedimentary rock rather than in granite.

ELASTIC POINT-SOURCE PROBLEM

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A derivation has been made of the surface motions of a three-dimensional semi-infinite elastic solid due to an impulsive internal point source of either P-wave type or S-wave type. Numerical results are given for both small and large epicenter distances.

NOTE ON REFRACTED WAVES IN A LAYER

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It is generally recognized that the wave length of a refracted wave must be small with respect to the thickness of the refracting layer if the observed velocity is to be the true velocity for the material in the layer, but no precise criteria have been given. Such criteria are derived, and it is shown that the long wave-length limit for true refracted waves is determined by the condition for constructive interference between the wave refracted through the layer and the wave reflected at the bottom of the layer. The correction to observed velocity to be made if scattering or absorption eliminate the shorter period waves is discussed.

SURFACE WAVES AND MANTLE STRUCTURE

Frank Press and Maurice Ewing
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Long Rayleigh waves were observed at Pasadena from the great earthquake of 15 August 1950, and reported in the Pasadena bulletin as R_3, R_4, R_5, and R_7. We find that all of these have the same dispersion. It is inverse dispersion, group velocities changing gradually from about 3.76 km/sec to about 3.50 km/sec as the period changes from 70 sec to 250 sec. The 70 sec waves are the shortest for which scattering at continental borders is negligible.

The observed dispersion is believed to be due to the gradual increase in shear-wave velocity with depth. Rough agreement with the observed dispersion is obtained from calculation of Rayleigh-wave velocities in a layer 300 km thick with a shear-wave velocity of 4.4 km/sec overlying a homogeneous substratum with shear-wave velocity 6.0 km/sec.

The relation to the dispersion of G waves is discussed.

PROGRESS REPORT ON SEISMOLOGICAL WORK BY THE U. S. COAST AND GEODETIC SURVEY DURING 1951

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The report summarizes seismological activities of the U. S. Coast and Geodetic Survey conducted by the Washington and San Francisco (Seismological Field Survey) offices. Activities include a world-wide telegraphic information service for the immediate location of strong earthquakes, operation of strong-motion and teleseismic stations, collection of descriptive information, processing of all types of data, publication of results, and a limited amount of research.

ABSTRACTS OF PAPERS SUBMITTED TO THE MEETING OF THE ROCKY MOUNTAIN SECTION AT SALT LAKE CITY, UTAH, MAY 8–10, 1952

PENNSYLVANIAN AND LOWER PERMIAN OF NORTHERN AND EASTERN WYOMING

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Deposition and distribution of Lower Pennsylvanian in Wyoming were affected by positive areas east and west of the State and in northeastern (Black Hills region) and southeastern (Laramie Mountain region) Wyoming. During Middle and Upper Pennsylvanian, the uplift to the west became more intense, and great thicknesses of clastics were deposited in Idaho, lesser amounts in western Wyoming. The sea retreated eastward as the uplift spread progressively in that direction, and western and northern Wyoming became land, remaining so throughout Lower Permian. Pronounced uplift of the Front Range began in Middle Pennsylvanian and exerted influence on Wyoming sedimentation into Lower Permian. The Laramie Mountain region was a northward prong of this element evidenced by relatively thin Casper formation along the west flank.

The Black Hills are reflected by post-Osagian—pre-Desmoinesian deposition. Continuous deposition apparently occurred in the Hartville region from Morrowan (?) to Leonardian with development of a probable Wolfcampian anhydrite basin.

Evidences of these uplifts are revealed from study of the distribution, lithology, and age of the Amsden, Tensleep, Casper, and Hartville formations. Redefinition of the base of Darton's Tensleep sandstone is proposed. Formation status for the Tensleep is suggested to include all units below the Permian red beds and above Amsden cherty carbonate rocks.

The Casper formation of the Laramie Mountains is tentatively divided into lower, middle, and upper divisions approximating Middle and Upper Pennsylvanian and Lower Permian. Sandstone units were derived from erosion of the Ancestral Rockies and Tensleep of northern and western Wyoming.

THRUST FAULTS SOUTH OF PARK CITY, UTAH*

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Two thrust faults, one above the other, have been mapped south of the Park City district, Utah, between Bonanza Flat and Pine Creek on the west and Dutch Hollow on the east. They have been arched by a small stock of diorite porphyry, so their outcrops form a discontinuous ringlike pattern. Each fault has thrust younger rocks over older. East of Bonanza Flat the upper thrust has brought Weber quartzite (Pennsylvanian) over Madison limestone (Mississippian), cutting out at least 1500 feet of intervening strata. In the same area, the lower thrust has brought Madison limestone over Tintic quartzite and possibly Precambrian tillite; the thickness cut out may amount to 1000 feet. South of Bonanza Flat the upper thrust has been removed by erosion; the lower thrust causes the Madison and younger Mississippian formations to rest on Tintic quartzite. In Dutch Hollow, east of the porphyry stock, a fault inferred to be the upper thrust marks the contact between a thinned section of Weber quartzite and metamorphosed shale and limestone of upper Mississippian age; the lower fault is cut out by the porphyry except in the head of Dutch Hollow where limestone correlated with the Madison rests on Tintic quartzite.

The faults dip northward under the Park City district, where, if their observed character persists, they may cut out beds that are potential ore horizons. On the other hand, breccias along them could be the loci of important ore deposits, as they have been on similar faults in the adjoining Cottonwood-American Fork district.

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GEOLOGY OF THE PRECAMBRIAN METAMORPHIC TERRANE, FARMINGTON MOUNTAINS, UTAH

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The northern Farmington Mountains, a division of the north-central Wasatch Mountains, Utah, are characterized by a well-exposed middle (?) Precambrian terrane. The Precambrian rocks are the products of progressive regional metamorphism and they are classified according to the concept of "mineral facies" of rocks as defined by Eskola. Seven metamorphic facies and subfacies are recognized in the terrane that range from low-grade progressive greenschist to the high-grade granulite.

Local bodies of moderately coarse-grained hornblende-biotite granite crop out in the terrane. Pegmatite dikes are widespread in the terrane, and two types of pegmatite are recognized—a gray soda-rich pegmatite in the progressive greenschist zone, and a pink potash-rich pegmatite common in the higher-grade zones.

Molecular values calculated from chemical data are plotted on a Niggli-Becke projection, as an aid to the classification of the rocks according to facies and origin.

Ten extensive thrust faults are exposed in the area, and the thrust faults are correlated with the lower Laramide thrust faults in the region. Zones of retrograde greenschist are well developed along all the thrust faults. Characteristic fabric of the diaphthorite is presented.

The mountains are essentially a composite series of north-northwest trending fault blocks bounded by normal faults. The mountains are bounded on the west by the great Wasatch fault system and on the east by a system of northwest-trending en echelon faults.

STRATIGRAPHY OF LAKE BONNEVILLE AND ASSOCIATED QUATERNARY DEPOSITS IN UTAH VALLEY, UTAH*

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Mapping in Utah Valley shows the following Quaternary stratigraphic section, which requires substantial revision of Gilbert's classic interpretation of Lake Bonneville history:

(1) Basal thick fan gravel, grading basinward to lake sediments; very strong soil profile on the gravel.

(2) Sediments of four high lake cycles (substages), which are Gilbert's ancient Lake Bonneville:

(a) First lake substage: Mainly silt and clay, some sand and gravel, to 5100 feet in maximum altitude.

(b) Local disconformity, eolian sand, alluvium, and/or weak soil profile, demonstrating lake recession to at least 4600 feet.

(c) Second lake substage: Mainly gravel, grading basinward to sand, silt, and clay; maximum level, 5135 feet, was Lake Bonneville's highest shore line (Gilbert's Bonneville shore line).

(d) Local disconformity, eolian sand, alluvium, and/or strong soil profile, demonstrating desiccation to at least 4500 feet (almost to bottom of Utah valley).

(e) Third lake substage: Gravel, sand, clay; major stillstand at highest level, 4800 feet, marked by large deltas and other shore features (Gilbert's Provo shore line).

(f) Local disconformity, alluvium, volcanic ash, and/or weak soil profile, demonstrating lake recession to at least 4700 feet.

(g) Fourth lake substage: Gravel, sand, and clay to about 4760 feet; final recession to below 4500 feet.

(3) Deposits of three low post-Bonneville lakes, with intervening alluvium, weak soils, and/or disconformities suggesting practically complete desiccation following fourth substage of Lake Bonneville and between each low-lake substage.

This record reveals that Lake Bonneville had four high cycles with partial recession between the first two and between the last two, and probably complete desiccation of Utah Valley between the second and third.

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GRANITIZATION IN THE SIERRA BATHOLITH AT MT. WHITNEY, CALIFORNIA

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A study of the publications on the Sierra batholith shows that, while this granite body is cited as an example of a typical plutonic complex, many of the writers have not been completely satisfied with the theory of magmatic differentiation as the unique solution to the problem of petrogenesis.

Petrographic evidence collected in the vicinity of Mt. Whitney indicates that, at the very least, one-fourth of the bulk of the granite of this area has been derived from pre-existing metamorphic rocks, that the mineral alterations followed in part a base-exchange pattern whereby andesine and biotite were altered to oligoclase, hornblende, and orthoclase, and finally that, while potash and soda traveled with a mobile or liquid fraction, other changes seemed to have been accomplished under solid or mushy conditions.

Albitic metacrysts which occur in the metamorphic border rocks survived the granitization process and are found, in somewhat reduced numbers, in the granite. Their relative abundance is used as a clue to the quantity of metamorphic rock altered to granite. Evidence for other mineral changes lies in the identification of certain mineral features which are interpreted as vestiges of reactions which did not go to completion.

A theory of cellular origin for the spectacular orthoclase metacrysts of the Cathedral Peak granite is presented.

SAPONITE NEAR MILFORD, UTAH

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A small deposit of a high-magnesium saponite has been found near Milford, Utah. It appears to have been formed as a result of hydrothermal replacement of dolomite. Differential thermal analysis, optical data, chemical analysis all prove the identification of this mineral as saponite. Electron-microscope pictures will be shown which show that saponite is a sheetlike mineral.

SLUMP STRUCTURES AND ASSOCIATED "CLASTIC INTRUSIONS" IN UPPER JURASSIC SEDIMENTS, KANE AND GARFIELD COUNTIES, UTAH

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Slump structures associated with pipelike, dikelike, and irregularly shaped bodies occur in the flat-lying Upper Jurassic sandstone and shales, southeast of Tropic, Utah.

The mutual relationship of these structures indicates they probably formed simultaneously in unconsolidated sediments. That they developed early in the history of the area, before the sediments were consolidated, is shown by their local occurrence and small scale, lack of relation to the regional tectonic pattern, restriction to certain zones in an otherwise conformable series of sediments, and indefinite and gradational contacts.

Structures showing several successive stages in the development of the collapse features and some indicating the probable origin of the clastic intrusions have been discovered. Evidence indicates the following sequence of events:

(1) Local small structural basins or synclines formed, due to partial removal of the underlying supporting material.

(2) These structures, with further removal of support, ruptured along their margins producing tilted interior blocks and grabenlike structures. Fluidized sandy sediments from below were injected into the ruptured overlying strata forming the clastic bodies.

(3) With further collapse, the sediments within the area of subsidence were disrupted and brecciated forming the clastic bodies composed mainly of angular fragments in a sandy matrix.

DIRECTION OF GLACIAL MOVEMENT IN NORTHERN MONTANA*

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Several types of glacial features indicate direction of ice movement across the plains of north-central and northeastern Montana: glacial striae, drumlins, drumlinized till, a boulder train, crevasse fillings, recessional moraines, and eskers.

Previous workers have reported bedrock striations at several localities near the Bearpaw Mountains. A boulder train trending southeast for 49 miles from Snake Butte has been described in the literature. More than 20 areas of drumlinized till, drumlins, and more than 13 localities of recessional moraines were observed and studied. Crevasse fillings cover two large areas. The western area extends 30 miles southeast from the town of Turner; the eastern area begins 10 miles southwest of Westby and ends 10 miles west of Frazer.

The directions of ice movement indicated by these features show that the continental ice sheet was forced to separate into several lobes by high areas such as the Sweetgrass Hills, the Bearpaw Mountains, the Little Rocky Mountains, Cherry Ridge, and the several driftless areas in the northeastern part of the State. One lobe of ice moved around the west side of the Sweetgrass Hills and southeast. Another, larger lobe moved around the east side of the Sweetgrass Hills and generally southeast until it was split into a western and an eastern lobe by the Bearpaw Mountains.

The western lobe moved generally southward toward the Highwood Mountains where most of it was diverted southwest toward Great Falls and the remainder southeast. The eastern lobe moved southeast past the Little Rockies and into the preglacial valley of the Musselshell River which is now occupied by Telegraph Creek. Another lobe moved south to Cherry Ridge and turned southeast to flow past Hinsdale and Glasgow; a lobe moved south down the Poplar River valley past Scobey; and a lobe flowed southwest from Westby up the preglacial Missouri River and west as far as Frazer. Thus there were six main paths of movement of the ice across Montana, rather than the general southwesterly direction of movement indicated by previous workers.

PLEISTOCENE GEOLOGY OF PART OF CENTRAL SOUTH DAKOTA*

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The region around Pierre, South Dakota, is bisected by the trench of the Missouri River, which forms a boundary between an area on the east that is mostly covered by glacial deposits overlying Upper Cretaceous Pierre shale and an area on the west directly underlain by shale.

The earliest Pleistocene deposits are remnants of stream alluvium derived from the region to the west. These are now perched on some of the highest knobs in the area and bear witness to an inversion of topography that was caused, in part, by a lowering of base level when the Missouri River trench was formed marginal to the glacier of the Illinoian stage.

In the Wisconsin stage, the glacier of the Iowan substage crossed the Missouri trench, and in one place extended 20 miles farther west. Each successive glacier extended a shorter distance west than its predecessor. The glacier of the Tazewell substage reached the Missouri River and during its retreat built two massive end moraines in the area. Deposits of this substage cover most of the area east of the Missouri. Till of the Cary substage is restricted to the northeast corner of the area; the drift border of the glacier of the Mankato substage lies about 15 miles east of the region investigated in detail.

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PRELIMINARY REPORT ON THE GEOLOGY AND ORE DEPOSITS OF THE GARFIELD QUADRANGLE, COLORADO

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The Garfield quadrangle, including the Tincup, Tomichi, Monarch, and Chalk Creek mining districts, and part of the Quartz Creek district, is within an extensively mineralized region in west-central Colorado and covers a part of the Sawatch Range where altitudes range from 9000 to 14,100 feet.

Ores valued at about $30,000,000 have been produced from about 225 mines within the quadrangle. Gold, silver, lead, zinc, and copper ores have accounted for most of this value, but small tonnages of tungsten, molybdenum, and beryllium ores also have been produced. Sphalerite and silver-bearing galena occurring as replacement bodies in limestone and dolomite and as shoots in pyritic quartz veins are the principal ore minerals; however, many other types of deposits with a variety of mineral assemblages are present in the region.

The rocks in the Garfield quadrangle fall into three main groups: schists, gneisses, and granites of Precambrian age; sedimentary formations that range in age from Cambrian to Cretaceous and total about 7000 feet in thickness; and andesitic to granitic intrusive rocks of probable Tertiary age, which form stocks, chonoliths, sills, and dikes, and one batholith.

The pre-Tertiary rocks are complexly folded and faulted; the major structures are northwest-trending folds and an east-trending graben that is cut in places by a northwest-trending thrust fault. The thrust fault has a probable maximum displacement of several miles.

From the geologic study made it is concluded that favorable areas for prospecting still remain, chiefly in faulted areas covered by surficial deposits. The most favorable areas are along South Arkansas River and Cree Creek.

CENOZOIC HISTORY OF MISSOULA VALLEY, MISSOULA COUNTY, MONTANA

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A preliminary report of some phases of the Cenozoic history of the Missoula Valley, Missoula County, in northwestern Montana is presented. The valley is probably of Laramide origin. Mid-Tertiary degradation resulted in formation of the "sub-summit surface" seen on mountains that surround the valley and contributed to deposition of Eocene (?) to Miocene (?) "lake beds" in the valley. Late Tertiary uplift rejuvenated streams, and the ancestral Bitterroot River was superimposed onto several spurs of Beltian bedrock that projected into the Missoula Valley. The "lake beds" in the valley have a marked secondary northward dip.

Pleistocene glaciers dammed the Clark Fork valley to the north creating glacial Lake Missoula. Subdued morainal deposits near Missoula, Montana are either from pre-latest Wisconsin advances or are due to subaqueous ice-edge deposits. Lake Missoula did not drain in one large flood. Its drainage was even, as very closely spaced beaches attest. The average minimum post-Pleistocene entrenchment of the Clark Fork River is 50 feet, and three sets of terraces have been developed.

SURFICIAL AND DEEP-SEATED TECTONICS OF THE GULF OF MEXICO AND CARIBBEAN REGION

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The Paleozoic sediments in the late Paleozoic belt of orogeny, which nearly surrounds the Gulf of Mexico, point to a source land in the site of the Gulf. The Mesozoic sediments in the late Mesozoic and Cenozoic belts of orogeny which surround the Caribbean Sea basin point to a source land in the site of the Caribbean. The major vertical movements and also the arcuate belts of profound horizonal compression are explained as follows:

The Gulf of Mexico was the site of gradual heating of the subcrustal material for the major part of the Paleozoic era, and as a result the crust above continued to rise, to be eroded, and to have

most of the sial stripped from it. By this time the subcrustal material had reached the molten stage, a major convection overturn occurred, and an arcuate orogenic belt was formed around three sides of the positive region. Cooling immediately started in the fluid of the overturn, and solidification and further contraction occurred. This was a long time of subsidence contrary in direction to the previous uplift, and the Gulf of Mexico came into existence. The high negative anomalies in the belts of compression have been adequately explained by Meinesz, and the subsidence of the arc-enclosed area with a very thin sial seems to explain the high positive anomalies of the basin floor. Isostatic adjustments due to the weight of great deltas have been superposed on the tectonic movements.

By late Jurassic time another convective overturn in the western Caribbean was about ready to take place, and approximately the history of the Gulf of Mexico was repeated. Then in early and middle Cenozoic time a third great overturn occurred in the eastern Caribbean when the arc of the Lesser Antilles and the eastern Caribbean basin came into existence.

SELENITE CRYSTALS IN THE CLAYS OF GREAT SALT LAKE

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Selenite crystals 2 to 6 inches long have recently been found in a few places around the shores of Great Salt Lake in the soft sodium clays of the lake bottom. No gypsum or anhydrite has been precipitated from the present lake waters. This occurrence may be significant in explaining the origin of selenite crystals in shales, so commonly seen on the erosion surfaces of shale formations in arid regions. Bacteria are believed to be the cause of a steady state in the clays conducive to the growth of the gypsum crystals, but physical changes incident to the consolidation of the clays may be significant.

DEFINITION OF A MINERAL BELT IN SOUTH-CENTRAL COLORADO

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A hydrothermal mineral belt in south-central Colorado may be defined by the intersection of early Eocene east-dipping thrusts with late Eocene southwest- and west-dipping thrusts in a zone trending southeast from Kerber Creek to Huerfano Park. West-directed movement in the north and east-directed movement in the south toward the old central Colorado basin formed structural intersections of probable deep penetration. Mineralized areas nearest the zone of intersection are Bonanza, Dennison City, Orient, Blake, Rito Alto, Westcliff, Silver Cliff, Rosita, the Marion mine, and Grayback. The Cleora, Badger Creek, Red Gulch, Currant Creek, and Grape Creek districts and numerous isolated prospects considerably northeast of the zone tend to obscure mineral-belt definition. However, the effects of severe deformation may extend northeast and southwest from the zone and could provide channels for igneous rocks and hydrothermal solutions. This would broaden the belt. The belt width appears to extend farther northeast than southwest from the zone probably because of excellent bedrock exposures in the Arkansas Canyon region between Salida and Canon City. Gravels of the San Luis and Wet Mountain valleys may conceal extensions of mineralization southwest of the zone except where it crosses the little-known Sangre de Cristo Range. Although structural depth penetration or insufficient quantities of source fluids may have allowed only scant mineralization except locally (Bonanza, Westcliff, and Silver Cliff), the low productivity of the belt may result in part from the lack of geologic investigation.

CRATER MOUND, ARIZONA—A GEOLOGIC FEATURE

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The crater and the mound are two separate features. The mound is the remnant of an elliptical dome with a crater in its apex. Originally the dome rose hundreds of feet higher. The huge blocks of arenaceous Kaibab limestone and some Coconino sandstone which occur out of normal position fell from high overturned walls. Much of the fine, white sand found on the rim is bedded, a product of weathering. The silica glass at Crater Mound is probably derived from explosive volcanoes to the northwest or southwest.

Crater Mound occurs exactly on the axis of Sunshine Nose; their axes coincide. A ring syncline with a northeast drainage outlet lies outside the rim from half to three-quarters of a mile from the Crater's center.

Two grabens, one on the north end, one on the south end of the mound, are remnants of a former single graben. Grabens and sinkholes are common in the area. The similarity of Crater Mound to faulted anticlines and domes in the Colorado Plateau area suggests a genetic relationship.

Applying the Theory of Multiple Hypotheses to origins, a tectonic-geomorphic origin is the most likely. Waters infiltrating down the faults aided solution, and disturbance of the regional water level by tectonic action accelerated subsurface action, with consequent subsidence.

The folding is probably late Tertiary of the order of 5,000,000 years, the crater of the order of 300,000 years, and the meteoritic fall, an adventitious occurrence, of the order of 50,000 years.

GLACIATION AND DRAINAGE CHANGES IN THE FISH LAKE PLATEAU, UTAH

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The Fish Lake Plateau, nearly centrally located among the High Plateaus of Utah, exhibits glacial and other geomorphic features of regional significance. The plateau is divided into two areas by the wide valleys of Fish Lake and Sevenmile Creek. The Fish Lake trough is a structural basin; Sevenmile Valley may be largely erosional. Volcanic rocks underlie most of the plateau; in addition, some early Tertiary sedimentary rocks are present. Glaciated canyons with well-developed cirques are especially prominent along the east-facing sides of the Fish Lake trough and Sevenmile Valley. Features indicative of ice scour cover much of the plateau top. Near the mouths of several of the glaciated canyons are two conspicuous sets of moraines—an older more extensive one at somewhat lower elevations and a younger more rugged one at higher elevations. Two substages of glaciation thus recognized are correlated with Wisconsin I and II of Ray; probable correlatives of Wisconsin III, IV, and V are represented by younger moraines. The present drainage of Fish Lake is northward where it joins that of the Fremont River, a tributary of the Colorado River. An abandoned southern outlet and waterfall, the latter at a higher elevation than the present elevation of the original northern bedrock divide, indicate drainage reversal. Evidence is presented to show that this reversal was preglacial and probably the result of regional tilting.

PETROGRAPHY OF THE TROCTOLITE OF THE WICHITA MOUNTAINS, OKLAHOMA, WITH REMARKS ON PREFERRED ORIENTATION OF OLIVINE CRYSTALS

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Troctolite outcrops of Precambrian age occur near Roosevelt in the central Wichita Mountains in southwestern Oklahoma.

The rock has an average composition of 68 per cent plagioclase (An_{72-80}), 26 per cent olivine (Fo_{73-80}), and 6 per cent diallage, hypersthene, and many accessory and secondary minerals.

Two mineralogical features are of particular petrogenetic significance: (1) The intergrowth of diopsidic lamellae (En_{75}) in hypersthene (Fs_{29}) is interpreted as due to exsolution of diopside attending on inversion of pigeonite to hypersthene. The inversion temperature of pyroxene of this composition has been determined experimentally by H. H. Hess as about 1100°C. This feature found in troctolite indicates that the magma had a temperature slightly above 1100°C. at the time of intrusion. (2) The occurrence of small to considerable amounts of spinel (pleonaste) indicates that the magma is abnormally rich in Al_2O_3, perhaps due to incorporation of aluminous sedimentary material at levels far below the present emplacement. Sillimanite found in the associated anorthosite also supports this view.

Two conclusions are reached as to the preferred orientation of the olivine crystals in the troctolite: (1) there is no preferred orientation of olivine crystals due to gravity settling; (2) concentration of α-axis of olivine crystals normal to the plane of banding, dimensional parallelism of minerals, and banding of the rocks are characters of troctolite fabrics produced by magmatic flow.

STRUCTURE AND MINERALIZATION OF A PORTION OF THE BALD MOUNTAIN MINING DISTRICT, SOUTH DAKOTA

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The Bald Mountain mining district lies on the western edge of the Precambrian core of the Northern Black Hills near Lead, South Dakota. Structurally, the district is located on gently dipping beds on the flank of a dome. The dome resulted from the forceful intrusion of magmas in the early Tertiary.

The material for this report was obtained from a study of a small portion of the district.

The ore deposits are localized along northeast-trending fracture zones as replacements in favorable horizons of the Cambrian Deadwood formation. The trend and character of the mineralized fracture zones are ascribed to the forceful intrusion of igneous material.

In great part the ores consist of gold-bearing, silica-pyrite replacements of dolomitic beds. In places, however, the basal quartzite has been mineralized and is mined locally.

Variations among the deposits of several horizons are correlated with differences in lithology and in response to deformation and mineralization.

PLEISTOCENE LAKE SEDIMENTS IN THE VICINITY OF SALT LAKE CITY, UTAH

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Restudy of the sediments of Lake Bonneville and older Pleistocene lacustrine deposits is in progress in the area of the Jordan (Salt Lake) Valley. Recent field and laboratory studies of these sediments in the vicinity of Salt Lake City, including sedimentological and micropaleontological analysis, indicate the following:

(1) The Bonneville stage of Lake Bonneville is represented in the area by shore-gravel remnants, and by current-built spits.

(2) Sediments of the Provo stage are quite thin in the Salt Lake City area and consist of (a) a thin carpet of near-shore gravels, bars, and local deltas, and (b) offshore silts and clays, with a distinctive ostracod fauna.

(3) The Provo stage shore gravels unconformably overlie the Alpine formation, a thick series of lake sediments consisting of (a) a near-shore gravel facies finer in texture than the Provo gravels, (b) an offshore series of finely laminated silts and lutites, with an abundant ostracod fauna quite different from the Provo fauna, and (c) local deltaic facies near the adjacent mountain valleys. Local mudflows occur in the Alpine at the eastern margin of the valley. The Alpine sediments are intimately associated with the terrace referred to as the "First Intermediate" by Gilbert.

(4) One of the most significant features of the Pleistocene lake sediments in the Salt Lake City area is the unconformity between the Alpine and post-Alpine sediments. The magnitude of this unconformity is evidenced by (a) well-developed soil profiles on the upper Alpine beds where they are overlain by Provo stage shore gravels, (b) the truncation of Alpine deltaic sediments by the Bonneville surface, (c) textural and microfaunal dissimilarities between the Alpine and post-Alpine sediments, and (d) discordances in dip between the Alpine lake deposits and the younger lake sediments.

FACTORS INVOLVED IN ESTIMATION OF BENTONITE RESOURCES*

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Estimation of ultimate tonnages of bentonite present and available for mining in any region or locality involves assumptions having to do with (1) bulk density of the raw material, (2) dimensions of mineable deposits, (3) character and thickness of overburden, (4) variations in quality of the clay with reference to current specifications for commercial material, and (5) probable revision of

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specifications as technology improves. Among the most critical factors affecting the computations involved are variations in purity, moisture content, colloidality, thickness, continuity, stratigraphic relations, and geologic structure of the deposits and the topography configuration of the lands they underlie. Uncertainties relating to such factors inevitably loom large in estimates of regional resources but can largely be dispelled within limited areas through intensive geologic, topographic, and laboratory investigation.

FAULT RELATIONS ON THE SOUTHEASTERN FLANK OF THE SHIRLEY MOUNTAINS, WYOMING

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The Shirley Mountains are a part of the Sweetwater arch located in central Wyoming. The area described is the upper Troublesome Creek basin and is bounded by heterogeneous Precambrian rocks, forming the core of the mountains, on the north; the Freezeout Hills on the east; the Hanna Basin on the south; and the Seminoe Mountains on the west. Paleozoic, Mesozoic, and Cenozoic sediments are present in the area.

An eastward-trending low-angle thrust fault extends through the southern portion of the area and places Precambrian rocks in fault contact with Upper Cretaceous sediments at the point of greatest apparent displacement. The youngest rocks involved in this disturbance are Early Cenozoic which dates the fault as Laramide.

There are at least five transverse faults, trending approximately N. 20°E., in the northern portion of the area. Evidence strongly suggests the continuation of these faults from disturbed areas of Paleozoic and Mesozoic sediments across the Precambrian core and into similar sediments in the Shirley Basin. Parallelism of these faults with a major joint system suggests control of this Laramide diastrophism by pre-existing basement planes of weakness. Anticlinal structures to the east are aligned with this major fault trend.

Paleozoic and Lower and Middle Mesozoic sediments are faulted by a system of eastward-trending normal faults. This normal faulting is the latest period of faulting. Evidence of other workers to the west suggests post-Miocene (?) adjustment of the Sweetwater arch by similar normal faulting.

GEOMORPHOLOGY OF THE SALT LAKE REGION, UTAH

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Salt Lake City occupies the northeastern portion of Jordan Valley, an intermont basin bounded on three sides by mountains. At the south lies the low, east-trending Traverse Range, which is divided into two unequal parts by the water gap of Jordan River, the northward-flowing outlet of Utah Lake. The Oquirrh Range borders Jordan Valley on the west, and the loftier Wasatch Range forms its eastern margin.

The Salt Lake region consists of three major geomorphic units, which in descending order of size are: (1) mountains, in an early mature stage of dissection; (2) an abandoned lake plain; and (3) an intervening pediment.

Remnants of old, submature erosion surfaces are still preserved at high levels in both the Wasatch and Oquirrh mountains. A complex Basin and Range-type fault zone is present at the western base of the Wasatch Range throughout most of its length; young fault scarps cut lake beds, moraines, and the most recent alluvial deposits.

The floor of Jordan Valley is a part of the recently abandoned bottom of late Pleistocene "Lake Bonneville." The plain is bordered on the west by a shallowly entrenched pediment carved on late Tertiary sediments and tuffs and thinly veneered with Pleistocene lake beds and Recent alluvium. East of Jordan River the piedmont zone is narrower and consists in the main of a downfaulted bajada, capped near the mouths of the larger canyons by coarse delta deposits and moraines left by late Wisconsin glaciers.

LONG-JAW GOMPHOTHERID MASTODON FROM MONTANA

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In April 1951 an almost complete skeleton of a mastodon of questionable geologic age was recovered from sands and gravels of a terrace 150 feet above the Clark Fork River near Deer Lodge in Powell County, Montana. Field investigations indicate that the enclosing sediments may be chronologically related to glacial deposits at the foot of the Flint Creek Mountains to the west, and that they may be genetically related to Pleistocene Lake Missoula.

Bunomastodont molars, long lower jaw and symphesis, and long, worn, lower incisors place this mastodon in the group of "shovel-tuskers" which are supposed to have become extinct in Pliocene time. The excellent preservation and completeness of the skeleton indicate that it cannot have been reworked from the Tertiary beds that constitute bedrock in the Deer Lodge valley. Possibly periglacial conditions in the northwest provided a more favorable habitat for these animals than existed in Pleistocene time in the Middle West and Great Plains areas from which the Tertiary specimens are known. Even without generic or specific identification this specimen is significant on at least two counts: (1) the long-jawed gomphotheres extended into Pleistocene time, and (2) the parallel development of the gomphotheres and the true elephants, and the independent ancestry of the latter, are further substantiated.

QUATERNARY EROSION FEATURES IN THE SOUTHWESTERN PART OF THE LARAMIE BASIN, WYOMING

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Geomorphic features within the southwestern Laramie Valley are of unusual interest and include: extensive remnants of three pediment levels, large deflation hollows, landslide phenomena, and glacial deposits. The Quaternary sequence of events can be well established by profile relations and statistical studies of gravel veneers. Precise dating is difficult because of shortness of the period and lack of fossils or alluvium accumulations, but some glacial evidence is available. Chronology includes:

(1) Erosion; nearly complete removal of Tertiary deposits.

(2) Stability of local base level across the valley with development of Table Mountain surface, a broad gravel-strewn pediment.

(3) Dissection of previous surface variably by deflation and stream activity creating Big Hollow, other blowouts, and new drainage trenches.

(4) Intermediate pediments cut to resulting lower base levels during deposition of early Wisconsin till.

(5) Dissection of Intermediate surface; further deflation.

(6) Development of pedimented Centennial surface bordering a Wisconsin II substage morainal front.

(7) Downcutting to present; Little Laramie flood plain intrenched in Centennial surface.

Since Quaternary warping is not indicated, cyclical dissection probably resulted from climatic changes attending the glacial epoch. Some control may have been effected by levels of the regional master stream gorge through the Laramie Range.

Pediments formed by lateral planation during cold periods when vegetation was lacking and streams were loaded; dissection occurred during warmer periods when more plentiful vegetation checked soil movement and allowed streams greater downcutting power. Present degradation is comparatively slight and is limited to occasional rain-torrent mud flows and slow corrasion of Centennial surface by braiding streams close to mountain fronts.

LATE QUATERNARY CLIMATIC HISTORY OF THE NORTHERN GREAT BASIN*

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The deposits of lakes Bonneville and Lahontan record similar sequences of lake cycles and inter-lake-cycle soil development, which show that the same succession of climatic changes affected both areas.

The record of fluctuating lake levels indicates changes in balance between precipitation and evaporation. Comparatively small increases in precipitation or decreases in evaporation from present rates could have developed the highest lakes within relatively short intervals of time. Comparison of volumes of Lahontan lakes and of tributary Sierra Nevadan glaciers shows that inflow came mainly from normal runoff within the drainage basin, with only negligible amounts from melting glaciers.

Available evidence suggests that, compared with the present climate, the lake-cycle climates progressed from warm-wet to cold-dry; the desiccation-interval climates progressed from cold-dry to warm-wet.

Complete desiccation between the second and third cycles of Lake Bonneville and between the first two cycles of Lake Lahontan confirms Richmond's interpretation of complete mid-Wisconsin deglaciation in the Rocky Mountains and suggests contemporaneous complete deglaciation of the Sierra Nevada. Partial recessions between the first two and between the last two Bonneville cycles, and within the first and between the last two Lahontan cycles coincide with partial deglaciation in the Rocky Mountains and probably also in the Sierra Nevada.

Post-Lake Lahontan stratigraphy confirms Antevs' interpretation of post-glacial climatic history of the Great Basin, except that it reveals a prominent dry interval preceding the first post-Lahontan lake, which is pre-Altithermal. Others have recognized this interval in the Rocky Mountains and in Nebraska.

STRATIGRAPHY OF LAKE LAHONTAN AND ASSOCIATED QUATERNARY DEPOSITS IN THE CARSON DESERT AREA, NEAR FALLON, NEVADA*

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Detailed mapping in the southern Carson Desert area shows the following stratigraphic section of Quaternary deposits:

(1) At base, thick fan gravel grading to shallow-lake sediments; very strong Brown Soil profile on the gravel.

(2) Sediments of several high-lake cycles (substages), which Russell defined collectively as Lake Lahontan:

(a) First lake substage: gravel, ranging to 4382 feet altitude, highest Lake Lahontan shore line; mainly boulder gravel, locally with lithoid tufa; offshore sand and clay rarely exposed, but encountered in wells.

(b) In highlands, eolian sand and alluvium with strong Brown Soil profile; in lowlands, shallow-lake sediments with local eolian sand and alluvium down to 3930 feet and swamp muck down to 3850 feet, indicating intermittent complete desiccation.

(c) Second lake substage: gravel, sand, and tufa on hill shores to 4370 feet altitude (contrary to Russell's interpretation that the second lake substage rose higher than the first); clay offshore.

(d) Local eolian sand and alluvium on hill shores, demonstrating lake recession to about 4050 feet.

(e) Third lake substage: gravel, sand, and tufa to about 4200 feet on hill shores; clay offshore conformable on second lake substage clay.

(3) Deposits of seven post-Lake Lahontan low lakes, separated by subaerial deposits and disconformities recording intervals of complete desiccation. High shore of first lake was 3975 feet;

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those of later lakes were successively a few feet lower. Before first lake and between first and second lakes extensive deflation and eolian deposition took place in lowlands, followed by weak Gray Desert profile development. Subsequent disconformities are less marked.

SOME URANIUM OCCURRENCES IN THE CENTRAL AND SOUTHWESTERN PARTS OF THE COLORADO MINERAL BELT*

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Recent discoveries of uranium in the Alma, St. Kevin, and Leadville mining districts of the central part, and in the Upper and Lower Uncompahgre, and Red Mountain mining districts of the southwestern part of the Colorado Mineral Belt have considerably increased the area within the Mineral Belt that warrants extensive prospecting for uranium deposits. The discoveries resulted from work undertaken by the U. S. Geological Survey for the Atomic Energy Commission.

Uranium minerals are associated with base- and precious-metal veins in the Alma, St. Kevin, and Lower Uncompahgre districts; and with pyritic veins and copper-lead-silver volcanic breccia pipe deposits in the Red Mountain district. They occur as coatings on fracture surfaces and as disseminations in country rocks in the Leadville, St. Kevin, and Upper Uncompahgre districts.

Pitchblende has been found in the Alma, Leadville, Upper and Lower Uncompahgre, and Red Mountain districts. Torbernite and pitchblende (?) occur in the St. Kevin district.

In the Lower Uncompahgre district, a genetic relationship between the uranium deposits and the zoning of metalliferous deposits related to the eruptive center of the Lower Uncompahgre district is suggested by the occurrence of uranium close to the boundary between a pyrite-gold-base-metal core and an outer silver-lead-zinc zone. No clearly defined zonal relationships were noted in the other districts.

The pitchblende(?) in the veins of the Red Mountain district, and in the Alma, St. Kevin, Leadville, and Upper and Lower Uncompahgre districts was probably deposited by hypogene processes. In the St. Kevin district, torbernite and sooty pitchblende(?) are alteration products of primary pitchblende(?). The origin of the high-grade copper-lead-silver breccia pipe deposits has previously been explained as caused by vaporization of ore solutions at high temperatures in a semisealed environment. Such an environment would be favorable for the retention of relatively soluble uranium compounds and may explain the association of the pitchblende(?) with the ore.

QUATERNARY STRATIGRAPHY OF THE LA SAL MOUNTAINS, UTAH*

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In the La Sal Mountains, eight cycles of Quaternary glacial and related deposits, separated by disconformities and soils, are recognized. Of two early stages, the older is more extensive. Its till retains no morainal topography; its outwash trends diagonally across present canyons. Till of the younger stage is locally morainal and was deposited in broad valleys. A very strong soil developed on both stages before canyon erosion. A third stage includes six substages:

(a) First and second substages: two lower canyon moraines, each with associated outwash, alluvium, slopewash, solifluction deposits, talus, and eolian sand. These substages are separated by a relatively weak soil or disconformity. A relatively strong soil is developed on the second substage and on exposed surfaces of the first.

(b) Third and fourth substages: two upper canyon moraines, each with associated outwash, alluvium, slopewash, solifluction deposits, talus, and eolian sand. Third overlies strong soil or disconformity on second; is separated from fourth by weak soil or disconformity. A moderate soil is developed on fourth and on exposed surfaces of third.

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(c) Fifth and sixth substages: two cirque moraines, each with associated outwash, alluvium, slopewash, solifluction deposits, talus, and eolian sand. Fifth overlies moderate soil or disconformity on fourth; is separated from sixth by weak soil or disconformity. Sixth has no soil, and some of its periglacial deposits are active.

The character and distribution of the third-stage soils suggest deglaciation between each substage, and a relatively long interstadial, warmer and at times wetter than the present, between the second and third substages.

CORRELATION OF THE LATE QUATERNARY DEPOSITS OF THE LA SAL MOUNTAINS, UTAH, AND OF LAKES BONNEVILLE AND LAHONTAN BY MEANS OF INTERSTADIAL SOILS*

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Late Quaternary sediments in the La Sal Mountains and in the basins of the extinct Lakes Bonneville and Lahontan contain four to six buried soil profiles. Although a given soil profile may change facies laterally as it passes from one soil-forming environment to another, it maintains about the same degree of development relative to the other soils. This coincidence of degree of development and stratigraphic position is found not only within each area but also among the three areas. The authors suggest, therefore, that the soil profiles are time markers and provide a means of regional correlation of the late Quaternary deposits. The relative development of soil profiles is the basis for the following correlation:

Standard sequence	*La Sal Mountains*	*Lake Bonneville*	*Lake Lahontan*
late Recent moraines	6th glacial substage		5th and younger lake substages
	very weak soil	younger lake substages	weak soil
Cochrane (?) substage	5th glacial substage		4th lake substage
moderate soil	moderate soil	moderate soil	very weak soil
Mankato substage	4th glacial substage	4th lake substage	3rd lake substage
weak (Two Creeks) soil	weak soil	weak soil	(disconformity)
Cary substage	3rd glacial substage	3rd lake substage	2nd lake substage
strong (Brady) soil	strong soil	strong soil	strong soil
Tazewell substage	2nd glacial substage	2nd lake substage	1st lake substage (double?)
weak soil	weak soil	weak soil	
Iowan substage	1st glacial substage	1st lake substage	
"gumbo" soil	very strong soil	very strong soil	very strong soil
pre-Wisconsin tills	two glacial stages	early fan-gravel	early fan-gravel

THRUST FAULTING IN THE ANTLER PEAK QUADRANGLE, NORTH-CENTRAL NEVADA*

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In the Antler Peak quadrangle, Nevada, rocks ranging from Early Ordovician to Permian (Phosphoria) have been complexly folded and thrust faulted. The rocks in the quadrangle have undergone two periods of major deformation, both accompanied by thrust faulting.

The first period of thrust faulting took place during the Antler orogeny which has been dated as probably late Mississippian. During this orogeny, strata ranging from Early Ordovician to Mississippian(?) were complexly folded and thrust faulted. The main structural feature formed was the Dewitt thrust fault. Folds in the upper plate of the Dewitt thrust fault are overturned to

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the east, indicating that the direction of movement was eastward; folds in the lower plate also appear to be overturned to the east. The amount of displacement on the thrust is conjectural, but may be 20 miles or more.

A second period of folding and thrust faulting occurred in Mesozoic(?) time; during this period the Golconda thrust fault was formed. In the Antler Peak quadrangle the upper plate of the Golconda thrust fault is composed of two formations, one of Pennsylvanian(?) and the other of early Permian(?) (Wolfcamp) age. These rocks are thrust over strata ranging from Early Ordovician to Permian (Phosphoria). Generally the rocks in the lower plate, near the thrust plane, dip gently westward; locally, however, they steepen and appear to be overturned to the east. The direction of movement of the upper plate of the Golconda thrust is clearly eastward, and it has brought together units of the same age but of entirely different lithology. The amount of displacement is at least 25 miles.

DISTRIBUTION OF CHERT AND IRONSTONE IN THE OSAGE GROUP (MISSISSIPPIAN) IN THE MISSISSIPPI VALLEY REGION

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Although the Montrose, Boone, Grand Falls, Burlington-Keokuk, and Fort Payne cherts have very similar lithologic, chemical, and associational characteristics, they have been described from a number of localities by separate investigators, with the result that several hypotheses regarding origin are found in the literature. Reviewed regionally, and related to lithofacies distribution in the Osage group, a common sedimentary origin appears probable.

The quantitative distribution of chert in limestone and the qualitative distribution of ironstone in the clastic sediments are both related to the facies-change interval from clastic to limestone lithofacies, and shown on a map. The chert and ironstone are considered to represent (in large part) primary sediments.

The silica is thought to have been transported as a hydrophilic colloidal hydrosol, surrounded by protective organic colloids; and the ferric hydroxide hydrosol carried as a hydrophobic colloid, similarly suspended by protective organic colloids. The colloids precipitated in sea water according to the Hardy-Schultze law, with the ferric hydroxide precipitating much more rapidly than the silica, which fact accounts, in part, for the spatial separation and distribution of the two sediments.

Evidence bearing on the sedimentary origin of the chert includes: position of chert concentrations; absence of gradational and replacement relations between chert and limestone; the uniform thickness of bands of chert or layers of nodules along a given bedding plane; the preservation of fossils in chert; curved, dehydration (?) cracks in chert nodules; and the remarkable purity of both rock types.

PROGRESS REPORT ON LIQUIDUS RELATIONS IN THE SYSTEM $MgSiO_3$-$FeSiO_3$-$CaSiO_3$

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A considerable body of data is available in the literature on the compositions and differentiation trends of natural pyroxenes, but these are complicated by the existence of partial solid solubilities between "end members," a wide variety of possible minor substitutions in the lattices, and the monoclinic⇌orthorhombic transformation. Experimental phase-equilibrium studies on the pyroxenes have been more or less limited to the sidelines of the system $MgSiO_3$-$FeSiO_3$-$CaSiO_3$, which represents essentially the compositions of the alumina-free pyroxenes. A number of ternary compositions with less than 50 mole per cent $CaSiO_3$ have been made to fall as closely as possible to this system, which is a plane through the tetrahedron representing the more general system MgO-FeO-CaO-SiO_2. Liquidus and solidus temperatures have been determined for the compositions, but at present no tie lines connecting the compositions of liquid and solid-solution crystals in equilibrium with each other have been established. The primary fields of olivine and of silica, representing nonternary equilibrium, encroach rather widely, and the melting intervals (solidus to liquidus) are small—usually less than 100°C. The exact positions of minima on the liquidus surface have not been determined, but the lowest temperatures found are near hedenbergite ($CaFeSi_2O_6$).

URANIFEROUS FLUORSPAR PIPES AND VEINS IN THE THOMAS RANGE, JUAB COUNTY, UTAH*

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U. S. Geological Survey, Denver, Colo.

Uraniferous fluorspar occurs in circular pipelike bodies, irregular pipelike bodies, and veins in the western part of the Thomas Range, Utah. This district, 6 miles long and 2 miles wide, has produced fluorspar since 1943. The deposits were examined by the U. S. Geological Survey on behalf of the Atomic Energy Commission.

The district is underlain by about 1600 feet of Silurian and Ordovician(?) dolomites, which conformably overlie 590 feet of Ordovician quartzite and about 100 feet of interbedded shale and dolomite. These rocks strike northeast, dip 20°–50° NW., and are complexly broken by large northeast-trending faults and smaller northwest-trending faults. Plugs and dikes of Tertiary rhyolite porphyry have intruded the dolomites.

The ore bodies in the southern part of the district occur in faults; in the northern part they occur in broken zones adjacent to the intrusions. The ore bodies dip steeply, cutting across the bedding of the dolomite, and terminate against the quartzite. The ore, a soft, pulverulent fluorspar ranging from white to dark purple, contains 65 to 95 per cent CaF_2, with clay, quartz, and calcite as impurities. Uranium constitutes 0.008 to 0.32 per cent of the ore. Pitchblende and carnotite, although rarely seen in the fluorspar ores, have been identified by laboratory studies. The radioactivity in many places is greater in the white fluorspar than in the dark-purple fluorspar.

BEDDING-PLANE FAULTS AT CABINET GORGE DAM, BONNER COUNTY, IDAHO

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Cabinet Gorge dam lies close to the Idaho-Montana line on the Clark Fork River in northern Idaho. A concrete arch-type dam 200 feet high is under construction by the Washington Water Power Company. The rocks are hard argillites of the Striped Peak formation of the Belt series. The major topographic forms owe their outlines to normal faults, but minor bedding-plane faults have caused the greatest trouble in the foundation. The beds dip about 12° NE., and the river has cut a canyon through three of these minor faults. They are spaced about 40 feet apart in the section. Movement ranges from a few inches to several feet, and the blocks moved updip indicating overthrusting. Thin, highly fractured, laminated rock characterizes those fault planes with little movement, but one with a larger displacement developed ½ to 2 inches of white clay gouge. Large joint blocks in the south abutment had slid toward the river by ice shove and gravity on this thin layer, thereby opening deep vertical cracks from a fraction of an inch to several inches wide in very sound rock. These cracks could have been grouted, but no economical way was found to remove the thin layer below them; hence it was necessary to remove many thousands of yards of otherwise sound rock and replace it with concrete. Diamond-drill holes rarely detect a clay seam this thin, with hard unshattered rock above and below it. Furthermore, without a large calyx drill hole or shaft, the presence of such clay is difficult to interpret.

COLLAPSE VERSUS EXPLOSIVE ORIGIN OF VALLES CALDERA, SANDOVAL COUNTY, NEW MEXICO†

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The Valles caldera, 30 miles west of Santa Fe, New Mexico, was first described by C. S. Ross (1931; 1938), who attributed it to a gigantic explosion. The caldera is nearly circular, averages 15 miles across, over 50 miles in circumference, and contains an area of about 175 square miles. Its

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† Ross, C. S. (1931) *The Valles Mountain volcanic center of New Mexico* (Abstract), Am. Geophys. Union, 12th Ann. Meeting, Tr., p. 185–186.
—— (1938) *Valles Volcano, New Mexico,* Washington Acad. Sci., Jour., vol. 28, no. 9, p. 417.

rim ranges from 8000 to 11,000 feet above sea level, and the walls reach a height of 2000 feet in places.

The geologic events were: (1) Growth of a volcano about 14,000 feet high of andesite and latite lavas and associated tuffs (Chacoma formation) in the Miocene (?); (2) Deposition of sediments (Santa Fe formation) in the Rio Grande Valley on its eastern base; (3) Cutting of radial canyons during the Plio-Pleistocene and deposition of detritus (Puye formation) on the warped Santa Fe formation; (4) Eruption of widespread basalt flows and a little ash from vents in the adjacent Rio Grande Valley and not related to the Valles volcano; (5) Collapse of the summit in the early Pleistocene(?) to form a huge caldera and concomitant violent rhyolitic explosions forming 15 fragmental cones and bulbous domes in, and close to, the caldera (Jemez formation). Accumulation of 500 feet of sediment in local lakes in Jemez and San Antonio valleys behind lava dams. Mud and nuée ardentes flows of ash were common; some are now welded tuffs. A long curved fault threw down the Pajarita Plateau 300 feet to further deepen the Rio Grande graben. Some tuffs were later, and some were earlier than the fault; (6) Recent erosion cutting box-headed canyons in the tuff and forming terraces in the Puye formation gravels.

The lack of great quantities of accessory ejecta in the tuffs forming the rim is proof that explosion was not the major cause of the caldera.

UNUSUAL GRAVEL AT THE STRIKE DAM, ELMORE COUNTY, IDAHO

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The Strike earth-fill dam has been recently completed by the Idaho Power Company on the Snake River, near Grandview, Idaho. The north abutment consists of a wide terrace of loose gravel and sand. When first explored with the usual diamond-drilling equipment, the logs indicated coarse alluvial detritus alternating with clay layers ranging from a fraction of an inch to several feet thick. No exposures were available as the entire area was covered with blow sand and loose gravel. The clay layers were so unusual in their distribution that deep test pits 8 feet in diameter were dug. The pits revealed well-rounded pebbles, cobbles, and boulders of clay up to 12 feet across, scattered among quartzite and basalt gravel. The whole deposit is the result of a catastrophic flood from the overflow of a temporary Pleistocene lake formed not far upstream by a lava dam. The clay boulders were made by the flood rolling along chunks of clay, eroded from the Pliocene Hagerman formation, which lay in its path. All gravel and boulders of clay had weathered to dust at the surface, but in the well-drained subsurface gravel they were still intact.

FIELDS OF FORMATION OF SOME COMMON DIAGNOSTIC HYDROTHERMAL-ALTERATION MINERALS

Bronson Stringham

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The problems of identification of the fine-grained hydrothermal alteration minerals are fairly well advanced. The temperature and pressure at which these minerals were formed is not so well known. Some common hydrothermal minerals are arranged on a chart, the abscissa of which represents the pH of the depositing solutions, while the ordinate represents temperature. The chart is presented with a multiple purpose—*i.e.*, to present in readily usable form the known information regarding the field of formation of minerals; to serve as a stimulus to students to attack the hydrothermal problem from a laboratory viewpoint; and to bring out further information from individuals who may have better data. It is expected that the chart will change from time to time with the accumulation of new information.

TWO URANIUM DEPOSITS IN SANDSTONE, WASHINGTON AND KANE COUNTIES, UTAH*

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U. S. Geological Survey, Denver, Colo.

Two deposits of oxidized uranium minerals have been investigated recently in the Silver Reef district in Washington County, and at the Bulloch properties in Kane County, Utah. These deposits were examined by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

The deposits at Silver Reef occur in the sandstone of the Chinle (Triassic) formation, near the nose of a breached anticline; a younger mass of trachyte porphyry, probably laccolithic, is located near by. The ore occurs as small lenticular deposits in the sandstone, and the principal minerals are carnotite, volborthite(?), copper carbonates, and in places horn silver. It is suggested that hydrothermal solutions from the consolidating trachyte porphyry produced the copper-vanadium-silver-uranium deposits.

At the Bulloch properties, disseminated autunite constitutes a blanket deposit in Jurassic sandstone just below the unconformity between the Jurassic and Cretaceous systems, and tyuyamunite occurs as grain coatings in the rocks just above the unconformity. Radioactive carbonized wood in clay pods occurs along the unconformity in close proximity to tyuyamunite and autunite. Igneous rocks do not crop out in the vicinity of the deposit, and the source of the uranium is not known.

HYDROGEOLOGICAL PROBLEM IN THE PROPOSED ECHO PARK RESERVOIR*

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The proposed Echo Park reservoir, on the Green River in northwestern Colorado, is admirably suited to storage of water with minimum losses by evaporation. However, a part of the reservoir area is underlain by cavernous Mississippian limestone, one of the most permeable formations in the region.

There are no measurable losses from the Green River into these limestones at low stage. The Green and Yampa rivers do lose water at flood stage as they cross the Uinta uplift—that is, between the Wyoming State line and Split Mountain on the Green, and below Cross Mountain on the Yampa. These losses range from 50,000 to 8,000 acre-feet each spring and are probably due in part to replacement of water taken by evapotranspiration from some 18,000 acres of flood-plain areas, especially in Browns Park, Island Park, and Lily Park. Gaging stations are not numerous enough to discriminate the losses, if any, by seepage into limestone.

Geologic conditions do not appear to be favorable for major losses from the reservoir by seepage into the limestone, but no guarantee can yet be made against such losses, because large areas underlain by the Mississippian limestone have not been mapped topographically or geologically.

DEEP WATER WELLS IN UTAH COUNTY, UTAH*

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Five deep wells drilled recently by Geneva Steel Company furnish most of the water needed for consumptive use at its steel plant in Utah Valley in north-central Utah. These wells yield more water by artesian flow than do wells tapping the shallower-developed aquifers, and the water is of better quality. On the other hand, a well 1250 feet deep in Cedar Valley (15 miles west of the Geneva Steel plant) penetrated chiefly fine-grained and poorly permeable sediments. It thus appears that the deep valley fill of Western basins may become an important new source of water in some places, but certainly not everywhere.

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The Geneva wells penetrated first the glacio-lacustrine deposits of the Pleistocene (Wisconsin stage) Lake Bonneville. Similar fine-textured materials were encountered at depths of 200 to 275 feet and 450 to 550 feet, and are evidently deposits in glacial lakes antedating Lake Bonneville. Between these lacustrine beds are the gravel and sand beds that form the two developed artesian aquifers in the area; these water-bearing materials were probably deposited during interglacial stages of the Pleistocene. The sediments at depths of 550 to 1200 feet include boulders, gravel, sand, and clay in discontinuous, poorly sorted beds, but no broad sheets of glacial lake deposits. Plant remains at several horizons indicate subaerial deposition. Volcanic detritus below 850 feet suggests the Pliocene (?) Salt Lake formation, which crops out 12 miles northwest of the steel plant. At the Cedar Valley well volcanic materials were found at several horizons below a depth of 140 feet.

NEW LIGHT ON THE APPALACHIAN GEOSYNCLINE

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New facts accumulated by field and laboratory work during the past 12 years suggest that it is unwise to use the names eugeosyncline and miogeosyncline in the Appalachian region. Furthermore, the geological history of the geosyncline north of Long Island was very different from that of the geosyncline south of Long Island.

The southern geosyncline had its inception in Algonkian time when its width took in a cross section from the present Fall Line near Baltimore, westward to eastern Ohio. An ancient intrageosynclinal welt existed on the site of the present Blue Ridge anticlinorium from Algonkian through Ordovician time. The area between this welt and Appalachia received thick accumulations of volcanic materials during Algonkian time especially in Maryland and Virginia. Farther south local basins accumulated the Lynchburg and the Ocoee sequences. The Cambro-Ordovician megacycle is characterized by thick accumulations of argillaceous sediments in the same general region.

Near the close of Ordovician time uplift between the welt and Appalachia produced a high and wide land mass from which the Silurian and later sediments were derived for the western part of the geosyncline. The Appalachian orogeny began in late Mississippian time, was repeated in early Pennsylvanian, and had a climax in middle Pennsylvanian time. The climax was marked by widespread metamorphism and structural deformation. Granitic plutons of large size account for granitization and migmatization so evident in the Piedmont. Early magmatic differentiation produced the ultrabasic rocks (ophiolites) so often mentioned in the literature as diagnostic features of a geosyncline. Best hint of their age has been found in the Port Deposit complex near Baltimore.

SOME RECENT RESULTS OF INVESTIGATIONS AT STEAMBOAT SPRINGS, NEVADA*

Donald E. White

U. S. Geological Survey, Carson City, Nev.

Steamboat Springs has had an involved geologic history, extending through a considerable part and possibly all of the Pleistocene. Most of the springs emerge from a system of north-striking and east-dipping normal faults of small displacement that are believed to be in the hanging-wall block of a west-dipping thrust fault.

Diamond drilling by the U. S. Geological Survey in 1951 revealed critical data on the structure, temperature relations, and alteration in the granitic and volcanic rocks which have been affected by the hydrothermal activity. Although study of the drill core is not yet completed, it is already clear that minerals produced by the several types of alteration include members of the kaolinite, illite, and chlorite groups, orthoclase (a small part with adularia habit), quartz, chalcedony, calcite, and pyrite. Other less abundant minerals are also found.

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RED ROCK PASS, OUTLET OF LAKE BONNEVILLE

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Late Pleistocene Lake Bonneville overflowed at the north end of Cache Valley across a low ridge connecting the Northern Malad Range on the west with the Portneuf Range on the east in T. 12 S., R. 38 E., Bannock County, Idaho. The outlet channel, where the lake waters spilled over the rim, is about 400 feet wide at the top and 500 feet deep.

The rim consists of Paleozoic shale, limestone, and dolomite dipping up to 60° E. and probably representing the Bloomington and Nounan formations (Cambrian). These are flanked by Tertiary conglomerates and tuffs of the Salt Lake group. The general strike of the Paleozoic rocks coincides with the trend of the channel. The presence of thick members of shale and thin-bedded limestone may have determined the lowest part of the rim, and permitted comparatively rapid lowering once outflow occurred there. The bottom of the channel is cut in Paleozoic rocks for approximately 2 miles.

The apex of the alluvial fan of Marsh Creek is approximately 3 miles north-northeast of the outlet, and the outer edge of the fan reached to the north base of the rim, but played no part in the history of the outlet except to be truncated by the discharging waters. A pass with elevation 5180 feet lies on the rim 1 mile east of the channel and shows no evidence of outflow.

The highest traces of the channel along the inside of the rim are approximately at elevation 5135 feet, and it is thought that the original elevation of the low point in the rim was near that figure. The well-developed shore features throughout the Bonneville Basin at the highest level of the lake seem to require that the highest lake was maintained at constant level by outflow. If so, this lake had little discharge and did little cutting on the rim. Later in its history this same lake may have spilled a much larger volume of water; or a subsequent lake may have reached the level of the rim with a large volume of discharge, and then rapid downcutting began. Each subsequent lake had a lower elevation. Marginal abandoned channels in the outlet indicate slight pauses in the downcutting and show that a considerable time was required for the lowering of the outlet.

LATE PRECAMBRIAN AND EARLY PALEOZOIC GEOLOGY OF THE WESTERN UINTA MOUNTAINS, UTAH

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Geologic mapping in the South Fork Basin of the western Uinta Mountains, Utah, has yielded data which permit a more accurate interpretation of the position of the Precambrian-Paleozoic contact. Two formations (Ophir and Pine Valley) heretofore assigned to the Cambrian, and thought to be conformable, are separated by a 20-degree angle of discordance. The plane of the unconformity is proposed as the proper position for the Precambrian contact. Rocks earlier mapped as the Ophir (?) formation of Cambrian age lie beneath the unconformity and are assigned to the Precambrian, and a new name proposed. Other lithic units have been recognized as distinctive formations in the upper Precambrian sequence, and names and correlations proposed. The oldest formation overlying the unconformity is Cambrian and is correlated with the Tintic quartzite of adjacent regions.

The Madison formation (Lower Mississippian) was deposited upon an erosional surface composed largely of Precambrian strata, partially of Cambrian strata, and locally of fossiliferous strata of Devonian or early Mississippian age. Accordingly, a pre-Madison period of uplift and erosion is postulated.

URANOPHANE DEPOSIT AT THE SILVER CLIFF MINE NEAR LUSK, NIOBRARA COUNTY, WYOMING*

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U. S. Geological Survey, Denver, Colo.

A uranium deposit at the Silver Cliff mine near Lusk, Wyoming, was examined by the Geological Survey on behalf of the Atomic Energy Commission. The deposit consists dominantly of uranophane that occurs as fracture fillings and small replacement pockets in faulted and fractured quartzite of Cambrian(?) age. The country rocks in the vicinity of the mine are Precambrian schist and pegmatite dikes and flat-lying Cambrian(?) quartzite that overlies the Precambrian rocks unconformably.

The mine is at the southern end of the Lusk dome, a local structure probably related to the Hartville uplift. In the immediate vicinity of the mine this dome is cut by the Silver Cliff fault, a north-trending high-angle reverse fault that has an approximate length of 1200 feet and a stratigraphic throw of 70 feet. Uranophane, metatorbernite, pitchblende, calcite, native silver, native copper, chalcocite, azurite, malachite, chrysocolla, and cuprite have been deposited in the fault zone and in fractured quartzite on the hanging wall.

The fault probably was mineralized throughout its length, but owing to erosion the mineralized zone now is discontinuous. The principal ore body, which has yielded all the uranium ore, is in the quartzite.

The uranium content of material sampled in the mine ranges from 0.001 to 0.23 per cent uranium, whereas that of dump samples ranges from 0.076 to 3.39 per cent uranium.

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ABSTRACTS OF PAPERS PRESENTED AT THE MEETING OF SECTION E, AAAS, IN ST. LOUIS, DECEMBER 29 AND 30

RHODONITE AT VANADIUM, NEW MEXICO

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Rhodonite occurs in the deep levels of the Star shaft of the Groundhog mine, the Hobo and Princess zinc mines at Vanadium, Grant County, New Mexico. It is probably an alteration product of a manganous pyroxene of the diopside-hedenbergite series, because the rhodonite contains numerous inclusions and is closely associated with the pyroxene. Sphalerite is the chief ore mineral; magnetite, specularite, pyrite, galena, and chalcopyrite are present in small amounts. Besides pyroxene, quartz, calcite, and garnet are the common gangue, but epidote and ilvaite occur with the ore minerals at other localities. The origin and mineral association of the rhodonite at these pyrometasomatic deposits will be discussed.

THRUST FAULTING NEAR THE HOT SPRINGS, HOT SPRINGS NATIONAL PARK, ARKANSAS

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Paleozoic strata form overturned folds with southwestward-plunging axes and southwestward-trending axial traces at Hot Springs National Park, Garland County, Arkansas. The southeastern flanks of the folds are overturned. The resistant Devonian-Mississippian Arkansas novaculite and overlying Mississippian Hot Springs sandstone form a series of zigzag ridges where the folds are eroded. Hot springs emerge from fissures in fractured Hot Springs sandstone on the northwest flank of the Hot Springs Mountain anticline. The spring-bearing belt of sandstone terminates about 1000 feet northeast of the northernmost hot spring, and younger, overlying Stanley shale is directly in contact with older, underlying Arkansas novaculite. The sandstone bed terminates where strata of the adjacent North Mountain syncline are thrust southeastward against the Hot Springs Mountain anticline. About 6600 feet northeast of the sandstone termination the North Mountain syncline abuts on the southeast directly against an overturned syncline. Abrupt termination of a prominent shale member of the Arkansas novaculite in the North Mountain syncline, lateral displacement of the crest of the mountain, and the traceable nature of beds in the adjacent syncline both in the field and on aerial photographs, indicate thrusting from the northwest.

At least two and possibly three additional southwest-trending faults appear on the southeastern flank of North Mountain and override, in whole or part, two additional minor synclines and two anticlines. The thrusts are of low angle and involve break-thrust, stretch-thrust, and subsequent shear-thrust characteristics. Maximum estimated displacement measured parallel to the dip of the thrust plane on the reconstructed thrust surface is about 1100 feet.

PETROLOGY OF THE STANLEY AND JACKFORK FORMATIONS, OUACHITA MOUNTAINS, ARKANSAS AND OKLAHOMA

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The Stanley and Jackfork formations (Late Mississippian-Early Pennsylvanian) constitute the thick, orogenic-phase filling of the Ouachita geosyncline. They attain a maximum thickness of 15,000–20,000 feet compared to 3000 feet of Cambrian through Mississippian sediments, and supposedly were derived from Llanoria, a borderland to the south.

The sandstones of the Stanley formation are graywackes, and those of the Jackfork subgraywackes.

Marked differences in mineralogy accompany this basic textural difference. The quartz grains of the Stanley sands are primarily of igneous derivation while those of the Jackfork are metasedimentary. The Stanley contains approximately 5% composite grains (rock fragments) and 5–15% feldspar as compared to 15% rock fragments and only 0 to 2% feldspar for the Jackfork. The roundness of grains in both sands is low. The sands of the Stanley are finer-grained and less well sorted than those of the Jackfork. They have bimodal grain-size distribution, and microscopic work suggests grading. The heavy-mineral suite of the Stanley includes garnet, rutile, zircon, apatite, and tourmaline, and that of the Jackfork zircon, tourmaline, and rutile. All lines of evidence suggest that the Stanley was derived from a source composed primarily of crystalline rocks and the Jackfork principally from metasediments.

The change in source that occurred during Stanley and Jackfork time was paralleled by an analogous change from deep- to shallow-water deposition. Both are closely related to the structural evolution of the geosyncline.

STUDY OF THE BEAR LODGE MOUNTAINS INTRUSIVE, WYOMING

B. W. Brown and A. L. Lugn
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The writer (B. W. Brown) has made an intensive study of the intrusive bodies and related Tertiary sediments in the southern Bear Lodge Mountains north of Sundance, Wyoming, and he expects to extend this study to include other Tertiary intrusives of the Black Hills region.

The Bear Lodge intrusive is a multi-stage igneous body similar in structure to Holmes' "cedar-tree" laccolith, modified by a disruptive stage of later igneous activity. The first stage of intrusion was a trachytic magma forming the main laccolith chamber and spreading laterally along planes of stratigraphic weakness, particularly in middle Deadwood members. The initial laccolith chamber was ruptured toward the northwest by an ascending trachyte magma that reached Triassic beds. The complex laccolith was shattered, ruptured, and transected by a relatively cool phonolite magma. Fractures in the trachyte were channels for the later mineralizing solutions which emanated from the cooling phonolite. The final tectonic event was the up-faulting of Sheep Mountain which, together with a regional uplift, occurred at the close of the Pliocene. Granitization of the invaded Deadwood formation is discussed, and mineralization in the Bear Lodge area is briefly reported.

SERVICE OF GEOLOGICAL SURVEYS TO THE GENERAL PUBLIC

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The prime function of the State Geological Survey is to give unbiased information concerning materials and conditions known to exist. In recognition of the value of such information, essentially every State Geological Survey is charged by legislative action to make its findings available for the general public. The Statutes of Missouri provide: "It shall be the duty of the State Geologist and his assistants to apply geologic principles to problems of agriculture, conservation, construction and other scientific matters that may be of practical importance and interest to the welfare of the state."

State geological surveys reach the public directly through weekly and monthly bulletins or newsletters, information services by office and field conferences, correspondence, news releases, and addresses before nontechnical groups. Exhibits are designed to portray local conditions. Road logs, guidebooks, and topographic maps are popular accessories for the tourist. Work books, popular publications of a semitechnical character, field conferences, and the sponsoring of lectures and work shops for science teachers have placed geology in the field of elementary education.

Many State surveys maintain repositories for stratigraphic, lithologic, paleontologic, and mineralogic materials. A few have established special facilities for the preservation of rock cuttings and cores from deep wells. Such records are now assured of preservation and accessibility.

STATE GEOLOGICAL SURVEYS AND MINERAL INDUSTRIES

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Discovery and efficient exploitation of mineral deposits and solution of beneficiation and processing problems require the combined efforts of geologists, geochemists, geophysicists, mining engineers, and management. Consumer specifications influence the price and demand for manufactured mineral products and may decide whether a new deposit can be developed. Continued use of a mineral commodity and development of new products usually result from increased knowledge of the origin, composition, and physical properties of minerals already on the market. To obtain industrially useful information about their respective mineral resources, State geological surveys are developing complex laboratories manned by such diverse scientists as botanists, chemists, physicists, engineers, and spectrographers, in addition to the fundamental research of their mineralogists, paleontologists, petrographers, physiographers, and stratigraphers. State surveys are thus accumulating large bodies of new geologic and mineralogic information that is immediately useful to the mineral industries. Effective use of this information requires continuous active co-operation of the technical personnel and managements of the mineral industries and of the geological surveys. Applications of the field and laboratory research of the State geological surveys are used to illustrate their usefulness to producers and consumers of industrial minerals.

INTERPRETATION OF THE ILLINOIAN GLACIATION IN FULTON COUNTY, ILLINOIS*

George E. Ekblaw and Harold R. Wanless
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In 1927, Wanless observed extensive sand and gravel and local varved deposits in the Havana quadrangle. In 1930, Ekblaw and H. A. Sellin noted that near Astoria the Buffalo Hart moraine overrode an older Illinoian moraine that trended southwest past Frederick and was tentatively ascribed to a glacier moving from the north and northwest. In a restudy of the Beardstown quadrangle in 1933, W. C. Krumbein obtained data suggesting that the Frederick glacier moved northwestward out of the Illinois River valley. Bedrock surface maps prepared by Wanless revealed northwest of Frederick a high bedrock ridge that would have hampered ice advance from the northwest.

Therefore Ekblaw and Wanless postulated that (1) the Frederick glacier protruded down the Illinois River valley and extended only 1–5 miles into the western uplands, (2) the pre-Frederick tributaries west of the valley were dammed, and in some of the resulting ponds or lakes varved deposits were laid down, (3) the ponded water escaped southwestward from one ponded tributary to another through a system of temporary spillways to the Illinois valley beyond the glacial front, (4) at some places new valleys were developed along the glacial margin, (5) outwash was deposited in some of these valleys and in some of the ponded tributaries, and (6) when the glacier melted some of the freed tributaries rejoined Illinois River through courses superposed on the bedrock flanks of their former valleys.

Joint field studies by Ekblaw, Wanless, and H. B. Willman in 1942 and 1943 revealed all these and other features that confirmed the hypothesis. Thus a local geologic problem of regional significance was resolved by results of a series of investigations, of which only the last was specifically a study of the problem.

GLACIATION OF THE MICHIGAN RIVER BASIN, NORTH PARK, COLORADO

Donald F. Eschman
Tufts College, Medford, Mass.

The Michigan River, a tributary of the North Platte, rises in the Cameron Pass area, where the Never Summer and Medicine Bow ranges join, and flows north and northwest across North Park.

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* Presented with the permission of the Chief, Illinois State Geological Survey.

Evidence of four glacial advances was found in the area. The earliest (Owl Mountain) stage is represented by a deeply weathered till of patchy distribution for the most part found in front of the mountains or high on valley walls, but in one place found within 3 feet of present stream grade. The second (Gould) glacial advance is marked by a nearly complete moraine at an elevation of about 9000 feet. The terminal moraines of the third advance (Silver Creek) are found a short distance upstream from the Gould moraine. Numerous recessional moraines were deposited by Silver Creek ice. The fourth and latest glacial advance (American Lakes) was a minor one, resulting in the deposition of formless deposits of fresh drift a short distance below the cirques. Protalus ramparts and rock streams were later produced while the climate was more rigorous than at present.

A 30-foot terrace and an 18–24-foot terrace along the Michigan River can be directly correlated with the Gould and Silver Creek moraines respectively. A still lower indistinct terrace may have been deposited during the American Lakes advance. No terrace can be correlated with the till deposits of Owl Mountain age.

The Owl Mountain stage is considered pre-Wisconsin, and the Gould, Silver Creek, and American Lakes deposits represent the Wisconsin.

SOURCES OF RECHARGE TO DEEP ARTESIAN AQUIFERS IN SOUTHEASTERN WISCONSIN

Frank C. Foley
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An essential part of a detailed study of the ground-water resources of the Milwaukee-Waukesha area, Wisconsin, was the location of recharge to the Ordovician and Cambrian artesian aquifers that are deeply buried near Lake Michigan. Analysis of pumping-test data in the Milwaukee-Waukesha area and study of piezometric profiles from Milwaukee to central Wisconsin, the areas of outcrop of the aquifers, show that water in the deep aquifers in southeastern Wisconsin enters the sandstones through the overlying Galena-Platteville dolomite where the dolomite is the bedrock immediately below the glacial drift cover. The piezometric profile slopes very gently westward from a crest in the area of outcrops of the Galena-Platteville. Recharge to the deep aquifers in southeastern Wisconsin does not take place in the areas of outcrop of those aquifers in central Wisconsin.

TRANSCURRENT FAULTING IN NEW ZEALAND TECTONICS

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Recent fault traces showing predominantly or exclusively strike-slip movement have been recognized in New Zealand for more than 60 years, but this type of faulting has been neglected in regional tectonic studies. A group of observers inspired by H. W. Wellman has now shown that transcurrent faulting is far more prevalent than previously believed. Several major active faults having a common strike trend have the same "sense" of relative displacement. For some the ratio of strike- to dip-slip component has not varied significantly for some thousands, if not tens of thousands of years. Stream-pattern adjustments in the Westland region are consistent with a lateral shift on the great Alpine fault of about 1 mile since the end of the Tertiary. The horizontal component of post-glacial shift, measured by the displacement of transverse river-terrace fronts, indicates the same order of velocity, and movement in the same sense. Structures composed of distinctive facies of Permian and Triassic rocks are offset 300 miles at the Alpine fault, and it is suggested that the post-Tertiary displacements mark the continuation of dominantly transcurrent movement that has peristed since perhaps the Jurassic. Accepted tectonic interpretations of the New Zealand sector of the Pacific margin are now likely to be reconsidered.

CAVES IN THE KINKAID LIMESTONE NEAR COBDEN, UNION COUNTY, ILLINOIS

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Several small caves occur in the Kinkaid limestone near Cobden, Union County, Illinois. The limestone is the highest formation of the Mississippian Chester Series. It overlies massive Chester sandstones and underlies massive Pennsylvanian sandstones. Together these formations form the cap of the south-facing Pottsville-Chester escarpment of southern Illinois.

The caves are joint controlled with open passages extending dominantly downdip in a northerly direction. Both longitudinal and network caves are represented. The entrances to the former are near stream level on the backslope, whereas the entrances to the latter are at a much higher elevation on the scarp face.

Clay, silt, sand, and cobbles partially or completely fill many passages. No large deposits of secondary carbonate are present except in the network of Lilly Cave.

The network caves high on the escarpment appear to have formed under phreatic conditions when the escarpment was remote. Fine-grained red clays were then deposited in the passages. Rejuvenation resulted in partial removal of the clay, but large quantities of debris were carried into the cave, ultimately nearly filling the passages. The last deposits are of silt derived from loess. Today underground water is once again flowing through many of the passages and removing the debris. Some additional solution is taking place along portions of several caves.

GEOLOGICAL RESEARCH ON GROUND-WATER RESOURCES

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Geological research on ground-water resources has expanded at an ever-increasing rate during the past two decades because of the greatly increased demands for water by industry, a growing awareness of its importance in economic development, and the successful application of techniques and skills in the solution of problems. Geological surveys play a major role in this research and in the rapid advancement of knowledge on water resources.

Research in ground-water geology has developed specialized techniques, principles, and personnel much as has petroleum geology. Early work in ground water was a minor adjunct to areal geologic studies, but later geologic investigations were carried on to obtain qualitative data on ground-water occurrence. Currently, many investigations utilize a background of engineering and mathematical approximations to obtain quantitative determination of interrelations between storage, recharge, and discharge. Seemingly, however, advances in the engineering aspects have not yet been accompanied by commensurate emphasis on geologic practices and reasoning.

Inasmuch as ground water occurs in, and its quality and availability are controlled largely by, the rocks, research in ground-water resources is pre-eminently a geologic problem that involves most technical phases of geology and much from related fields of engineering, chemistry, physics, mathematics, and soil science. An investigation of ground water requires a thorough knowledge of the thickness, areal extent, lithology and mineralogy, geologic history, correlation, structural relations, and facies changes for rock formations such as is determined by application of well-known techniques of surface and subsurface stratigraphy, sedimentology, petrology, and structural geology supplemented by some aspects of geomorphology, geochemistry, geophysics, and pedology. These data then are an essential basis for further hydrologic study and interpretation of the ground-water conditions. It is evident, therefore, that geologic research not only is fundamental in ground-water investigations but that adequately planned ground-water studies contribute importantly to fundamental geologic knowledge.

INTERRELATIONS OF ROCKY MOUNTAIN AND CONTINENTAL GLACIAL DRIFTS IN THE WATERTON REGION, ALBERTA

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Geomorphic, pedologic, and stratigraphic relations indicate the following Pleistocene drift sequence and tentative correlations:

(1) Cirque moraines and related deposits; slightly weathered (Little Ice Age).
(2) Keewatin drift; shallow youthful-weathering profiles (Cary).
(3) Late Wisconsin mountain drift; shallow youthful profiles (Cary; Pinedale).
(4) Early Wisconsin mountain drift; moderate youthful profiles (Tazewell-Iowan; Bull Lake).
(5) Kennedy mountain drift; deep old-age profiles (Kansan).

A buried soil between (4) and (5) may correlate with combined Yarmouth and Sangamon profiles in the Mississippi Valley, and a younger buried soil between (2) and (4) may be equivalent to the Brady soil of Kansas and Nebraska.

POST-CARY GLACIAL SUBSTAGES AND LAKE LEVELS OF THE LAKE MICHIGAN BASIN

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A sequence of lake stages in the Lake Michigan basin is set up, covering the time since the Cary glacial substage. Recent revisions in the lake history made by Stanley, Bretz, and the writer are incorporated in this sequence. Dates of events occurring in post-Cary time, obtained by two radioactive dating methods and reported by Libby, by Urry, and by the writer, are accepted.

During this sequence of lake stages two separate glacial substages, the Mankato and Valders, occurred, with their climaxes at 15,000 and at 11,000 years ago. Between the Mankato and Valders the lake basin was free of ice, the lake level was extremely low, and something, possibly invading marine water, gave a red color to the lake clays. Over-riding of the red clays by Valders ice gave the Valders drift its red color. Ice was present north of Lake Huron and in the Lake Superior basin at the time of the highest Algonquin lake stage, only 3500 years ago. When recession of the ice cleared the North Bay outlet (less than 3500 years ago) there was another low stage in which the lake surface fell to 350 feet below present level. Upwarp of the land to the northeast, beginning at this late date, raised the lake surface to the level of the Port Huron outlet, producing the Nipissing Great Lakes.

DUNE TOPOGRAPHY EAST OF COLORADO SPRINGS, COLORADO

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Extending east, northeast, and southeast from Colorado Springs, Colorado, is an area of over 500 square miles, characterized by a dune topography. The dunes are post-Pliocene but pre-middle Pleistocene. Inasmuch as they are almost completely grass-covered today, it is believed that they represent evidence of a significant climatic change in that part of Colorado in the fairly recent past. It is also believed that their distribution is one of the fundamental factors in the interpretation of pediment development in that area.

STRATIGRAPHY OF THE SHAWNEE ROCKS, OF PENNSYLVANIAN AGE, IN IOWA*

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The stratigraphy of the Shawnee rocks (Pennsylvanian) has been described in considerable detail for Kansas and Nebraska, and the general features of their occurrence in southwestern Iowa were

* Publication authorized by the U. S. Geological Survey, the Iowa Geological Survey, and the Iowa Highway Commission.

described in 1937 by Condra and Reed. The paucity of adequate exposures and the general lithologic and faunal similarities of the corresponding members in successive megacyclothems, however, warranted only doubtful identification of the beds at many Iowa localities. Recent study of all available exposures in Iowa, including a number of new sections supplemented by well and core data, permits reliable correlation of the formations and members throughout the State. It is proposed that the Shawnee be established as a group in Iowa because the numerous members of the four limestone formations, as recognized in adjacent States, are well developed and are characterized by distinguishing lithologic features and faunal assemblages. Within the outcrop area some members of the limestone formations are remarkably persistent, though in others changes are noted. The three intervening shale formations are thin and lack sandy phases.

ECONOMIC IMPORTANCE OF MEG. B-8, AN E-W ZONE OF CRUSTAL MEGASHEARING

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Some evidence is presented on the giant shear zone which crosses this continent from the vicinity of Norfolk, Virginia, to the great sunken area of middle California. The trend is plainly marked at intervals by numerous recognized distortions due to vulcanism, and by many evidences of deep crustal penetration: pegmatites, igneous intrusions, hot springs, crypto-volcanoes, earthquake paths, fault zones, diatremes, igneous plugs and dikes, ancient craters, lava flows—and at either end of this megastructure a large area of pronounced crustal sinking.

Included within this long but comparatively narrow belt are more than 20 important mineralized areas. Some have been classed as magmatic, others as hypothermal, and more as originally related to vulcanism or to the movements that it caused.

Through many decades, scores of famous mines within this belt have supplied minerals whose total value is in the billions of dollars; but production of the five leading minerals alone (gold, silver, copper, lead, zinc) still continues in this belt at the rate of over $100,000,000 per year.

An interesting comparison is made between the average production of the five leading metals alone per square mile within this belt of disturbance, and that of all the minerals per square mile in all the rest of this United States.

Even where this belt crosses certain so-called stable areas, the very slow movements in the rocks have shaped uncounted minor structures in the strata that trapped petroleum in such quantities that now, after 50 years, production still continues at the rate of 24 million barrels per year, from wells within this belt in a single State. And farther west in the same State, a single structure produces natural gas at the rate of 311 billion cubic feet per year. Thus the world's largest gas field also is situated largely within this east-west zone of crustal megashearing.

CONTRIBUTIONS OF GEOLOGICAL SURVEYS TO BASIC RESEARCH

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Geological Surveys should be intensive research institutions with laboratories designed for their special purposes, as well as serving as sources of information for the development of the mineral resources of their States.

Geological Surveys during the past have generally regarded geological mapping and interpretation of field phenomena as basic research, but the world of technology of the present requires much more information from other lines of basic research.

New fundamental information is needed on the physical and chemical nature of materials, including their atomic structure, to aid in the discovery of additional metallic and petroliferous resources and, in the field of industrial minerals, to ascertain what deposits are adaptable to meet precise specifications and to ascertain what processes of beneficiation are feasible and economic to convert the raw mineral substances into a usable product.

Laboratories of paleontology and petrography must be supplemented by chemical, spectrographic,

and X-ray laboratories, and basic research is required on the physical and chemical properties of earth materials to advance the use of geophysics and geochemistry in finding commercial deposits hitherto unknown. Examples will be cited of basic research in coal, clay mineralogy, and carbonates by the Illinois Survey.

OCCURRENCE AND SIGNIFICANCE OF TERTIARY DEPOSITS IN THE BEAR LODGE MOUNTAINS, WYOMING

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Darton and others recognized and mapped extensive areas of Tertiary surface and sediments (White River, Mountain Meadow) in the Black Hills and adjacent areas. Mostly, such areas retain only residual deposits of gravel, sand, and silt, generally believed to be of Oligocene age.

During the summer of 1951 B. W. Brown located two significant occurrences of Tertiary sediments at an elevation of about 5600 feet above sea level on the northwest slope of the Bear Lodge Mountains, Wyoming. The writers studied these outcrops then and again during the past field season. The total thicknesses of the Tertiary beds in these outcrops are 75 and 126 feet respectively. The lower gravels (3 to 10 feet), which rest on trachyte of the Bear Lodge Mountain intrusive, appear to be of Chadron age. Next above the gravels occurs some 60 to 120 feet of Brule clay, mainly the Whitney member (*Leptauchenia* zone). A significant erosional unconformity separates the Whitney member from 11 to 16 feet of overlying Ogallala "mortar beds" of the lower Ash Hollow formation, which contain the index fossil seeds *Biorbia fossilia* and *Stipidium commune*. The Ash Hollow remnants contain large amounts of gravel pebbles derived from the sanidine trachyte of the intrusive exposed in Warren Peaks to the east-southeast.

The significance of this rather unusual and unexpected occurrence of Tertiary deposits, especially of remnants of the Pliocene Ogallala group, is that it profoundly affects the geomorphological interpretation of the entire region of the Black Hills and the northern Great Plains. Tertiary sedimentation must then have begun in Oligocene (Chadron) time on a more or less graded plain, and it terminated in or at the close of Pliocene (Ogallala) time. Important unconformities are evident within the Tertiary deposits.

ROLE OF GEOLOGICAL SURVEYS IN PROBLEMS OF ENGINEERING GEOLOGY

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The role of a State Geological Survey in any problem is primarily that of service. Such service requires the collection, digestion, organization, and distribution of basic geologic data. Since the engineering geologist and the engineer are confronted with a wide variety of problems, it is conceivable that almost any kind of basic geologic information may be of use to them.

The chief concern of the modern Geological Survey in this field is therefore the same as in the fields of mining geology, petroleum geology, public-information service, etc.—that is, the accumulation of as much basic geologic information as is possible.

To serve the field of engineering geology further, some Surveys have special sections whose chief function is to anticipate the needs of engineers and to have geologic information so organized as to be of immediate use for this specialized field.

A number of examples from actual practice are cited.

CORRELATION OF GEOLOGY AND GEOPHYSICAL DATA IN THE SEARCH OF MISSISSIPPI LEAD DEPOSITS

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The correlation of geology and geophysical data has been quite helpful in the search for new lead deposits in the Southeastern Missouri Lead District of the Mississippi Lead Deposits. Geological

field mapping gives a limited amount of information for the search of the lead deposits. However, air and ground magnetic results have shown a definite correlation with major structural features and buried igneous ridges and knobs associated with the lead deposits. Favorable structural features are mapped by magnetics; electrical resistivity measurements are then made to: (1) determine the depth to the buried igneous masses, (2) measure the depths to and map major stratigraphic contacts in the sediments overlying the igneous rocks, and (3) detect fracturing, which favors mineral deposition. Drilling is recommended on the most favorable locations.

These geophysical methods and the correlation of their results with geological features have been quite helpful both in searching for new lead deposits and in the extension of known lead ore bodies.

PETROLOGY AND SEDIMENTATION OF UPPER CHESTER SANDSTONES*

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A systematic study of the mineral constituents and textures of upper Chester sandstones in Illinois and adjacent areas was undertaken to throw light on environments of deposition, tectonic activity, and possible sources of clastic material. The sandstones studied include those from the Tar Springs, Waltersburg, Menard, Palestine, Clore, Degonia, and Kinkaid formations. Methods of study other than ordinary subsurface geologic methods included thin-section, heavy-mineral, and clay-mineral analysis.

Although there are many minor facies changes in all these sandstone beds, all except the Menard and Kinkaid sandstones are persistent over wide areas in the Eastern Interior Basin, irrespective of whether the beds are massive or thinly interbedded with shale. Superimposed on the minor facies changes which occur laterally over short distances are major regional facies changes. The Menard, Clore, and Kinkaid sandstones are parts of formations composed predominantly of limestone and shale. The other sandstones are major parts of sandstone-shale formations.

Most of the sandstone beds are dominantly quartzose, with minor admixtures of clay minerals, carbonate, rock fragments, and accessory minerals. Most of the sandstones are well-sorted, clean orthoquartzites, but there are many occurrences of sandstones whose mineral compositions lie between clean orthoquartzite and moderately "dirty" subgraywacke. In some areas the youngest Chester sandstones are less mature than those lower in the section. Many of the sandstones show evidence of having been winnowed and reworked on the site of deposition before burial. The sedimentary environment, source areas, and tectonics are reconstructed from the information supplied by subsurface stratigraphy and sedimentary petrography.

STUDIES ON THE ORIGIN OF PETROLEUM: OCCURRENCE OF HYDROCARBONS IN RECENT MARINE SEDIMENTS

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The failure of past investigators to detect liquid hydrocarbons in recent sediments has been used to support the widely held contention that petroleum does not form in sediments at the time of deposition of the organic source material. The preferred viewpoint has visualized burial of the original "complex organic matter" by several thousands of feet of overburden and the elapsing of several millions of years as requisites for its conversion into hydrocarbons.

An investigation of the nature of the organic matter deposited in recent sediments has resulted in the discovery of liquid hydrocarbons in a wide variety of marine muds. Paraffinic, naphthenic, and a variety of aromatic components have been detected. The quantity of free hydrocarbons has varied from 9 to 283 parts per million of dried sediment. Extrapolation of data obtained on a 106-foot core taken from the floor of the Gulf of Mexico 7 miles off Grande Isle, Louisiana, would give

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an estimate of 4,500,000 barrels of crude oil per cubic mile of sediments in this area. Since the concentration of hydrocarbons increases with depth in this core, the above is probably a conservative estimate.

The recent origin of these hydrocarbons has been established by carbon 14 analysis.

ADDITIONAL FACTS CONCERNING THE AGE AND ORIGIN OF THE TYPE SECTION OF THE DAKOTA STAGE

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Twenty-one years ago the writer published detailed sections of Cretaceous rocks exposed in Dakota County, northeast Nebraska, and adjacent Sioux City, Iowa. These sections include the type locality of the Dakota as defined by Meek and Hayden. The conditions of sedimentation were interpreted, and the age was determined as equivalent to the Mentor member of the Lower Cretaceous Washita of north-central Kansas.

Restudy of the sections confirms the major conclusions of the original report. Additional facts are presented to support the assignment of the Dakota to the Lower Cretaceous. A microfauna has been identified in the beds immediately above the zone which contains the Mentor macrofauna listed in 1931. Foraminifera occur in several sections of the locality, and two shale zones contain an abundance of specimens. The Lower Cretaceous species *Trochammina depressa* Lozo is the most common of stratigraphic permanence, but at least three new forms of *Ammobaculites* of Early Cretaceous aspect have been studied.

SOME PROBLEMS OF THE BRIAN HEAD (TERTIARY) FORMATION IN SOUTHWESTERN UTAH

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In the southern High Plateaus of Utah, the pink and white marlstones of the (late Cretaceous-early Tertiary) Wasatch formation are separated stratigraphically from a group of (early to middle Tertiary) rhyo-dacitic flows and welded tuffs by a sequence of weakly consolidated pyroclastic and volcanic-derived sedimentary rocks which H. E. Gregory named the Brian Head formation. At the type locality, Brian Head Peak at the north rim of Cedar Breaks National Monument, the formation includes about 500 feet of interbedded volcanic ash and chalcedony, dacite lava, andesite breccia, and sheeted rhyolitic vitrophyre and tuff.

When the type locality and adjacent areas are studied in detail, the sheeted vitrophyre at the top of the type section is seen to be a glassy basal zone of the rhyolitic welded tuff caprock of Brian Head Peak. The andesite breccia and dacite lava immediately beneath the sheeted vitrophyre are a local agglomeratic phase of massive andesite lavas which constitute the basal formation in the group of Tertiary flows and welded tuffs which cap the southern High Plateaus.

Inasmuch as the type Brian Head formation includes a considerable thickness of rocks which are clearly part of the overlying group of flows and welded tuffs, it seems appropriate that the designation of Brian Head formation should be restricted, redefined, or abandoned.

AGE DETERMINATION OF DEEP-SEA CORES—THE IONIUM METHOD

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In an effort to date events evidenced in deep ocean cores, a detailed study is being made of the Ionium method of age determination. Decrease of the ionium content with depth in a core, following what appears to be the approach to equilibrium of radium and ionium, has been confirmed by the

use of an unusually homogeneous core from the Caribbean. Similar studies on cores obtained from the north Atlantic Ocean indicate the same general variation of ionium with depth, but, due to heterogeneity of core material and inconsistency of depositional rate, the data show considerable deviations from the smooth curve.

Carbon 14 age measurements on samples from the same cores help define the limitations of the Ionium method. In the case of homogeneous cores to which the Ionium method may be applied, the agreement between carbon 14 and ionium dates suggests that the cosmic ray flux has been essentially constant over the last 30,000 years.

MINERAL RESOURCES IN THE INDUSTRIAL DEVELOPMENT OF THE UPPER MISSISSIPPI VALLEY

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This paper discusses minerals as a means of creating and sustaining a high level of productivity by man in manufacturing, in agriculture, and in transportation. Economic development and the growth of the industrial and agricultural pattern in the Upper Mississippi Valley afford an opportunity to examine in some detail the pattern of industrial development in this area and the important role of minerals in creating productive employment and in serving as the vehicles for the production of wealth. The agricultural industry is included since minerals make important contributions to high productivity in this industry through mineral soil foods, mineral fungicides and pesticides to protect the growing crops, and power-driven machinery to increase the output of the farm operator.

The role of minerals in this area is evaluated by the increasing importance of structures in an industrial economy to include not merely shelter but warehousing, foundations for heavy transportation loads, industrial and commercial housing, and structural materials designed to withstand high temperatures or chemical action.

The role of fuels in the economy of the Upper Mississippi Valley discloses not only the large quantities needed but the high degree of fuel preparation and specialization needed for the many types of power machines and heat-using processes.

Finally the writer points to the role of high industrial productivity as essential to widespread educational opportunity, extending medical services and cultural growth.

EARLY AMERICAN GEOLOGY

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Geologists and historians of science little realize that during the Colonial period geological observations, some of considerable importance, were early recorded and continued to be made at increasingly frequent intervals. The Sir Humphrey Gilbert expedition of 1583 included "the minerall man and refiner . . . Saxon borne, honest and religious, named Daniel". The mineral man, his samples and information, and Sir Humphrey were lost in a shipwreck on the return to England.

Captain Vaughan was "mineral man" with the Raleigh expedition to Virginia in 1585. Thomas Hariot, historian and scientific observer of the expedition, published in 1588 probably the first geological observations about what is now the United States. He described the Coastal Plain, the Fall Line, iron ore, copper, clay for brick making, and appears to have recognized the fossils of the Coastal Plain sediments. Captain John Smith and other early travellers to Virginia from 1602 to 1620 published several geological observations. Publications continued at increasing frequency.

About 1750 penetrating and extensive observations were recorded by Kalm, by Bartram, and by Evans. Evans made geological cross sections and proposed respectable theories, including one on isostasy. The early nineteenth century geology of Mitchill, Maclure, and others did not originate from a vacuum but was based on more than 200 years of earlier work, some of it as fully advanced for its time as was the geological work of the old world.

CHARACTERISTICS OF WISCONSIN TILLS IN NORTHEASTERN OHIO

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As a result of field mapping and laboratory study, Tazewell, early Cary, and late Cary till sheets have been distinguished in the Allegheny plateau of northeastern Ohio. These tills can be separated by areal pattern and superposition and are characterized by variations in weathering profiles, soils, composition, and texture.

The Tazewell till is generally leached 6½ feet, the early Cary 4½ feet, and the late Cary 2½ to 3½ feet; the variation is apparently a function of permeability as well as of age. The soils of the Tazewell are Wooster (?); of early Cary are Wooster-Canfield-Ravenna; those of the late Cary are Ellsworth-Mahoning-Trumbull. The lithologic content is variable, but the variations require further study.

Mechanical analyses of over 100 samples show not only that the texture is remarkably distinctive and uniform for each till in the Killbuck and Grand River lobes, but also that the textural character of each till persists over distances of at least 75 miles, and probably much farther. The Tazewell averages 50% sand, 35% silt, 15% clay; the early Cary 30%, 45%, 25%; the late Cary 15%, 40%, 45%, respectively.

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